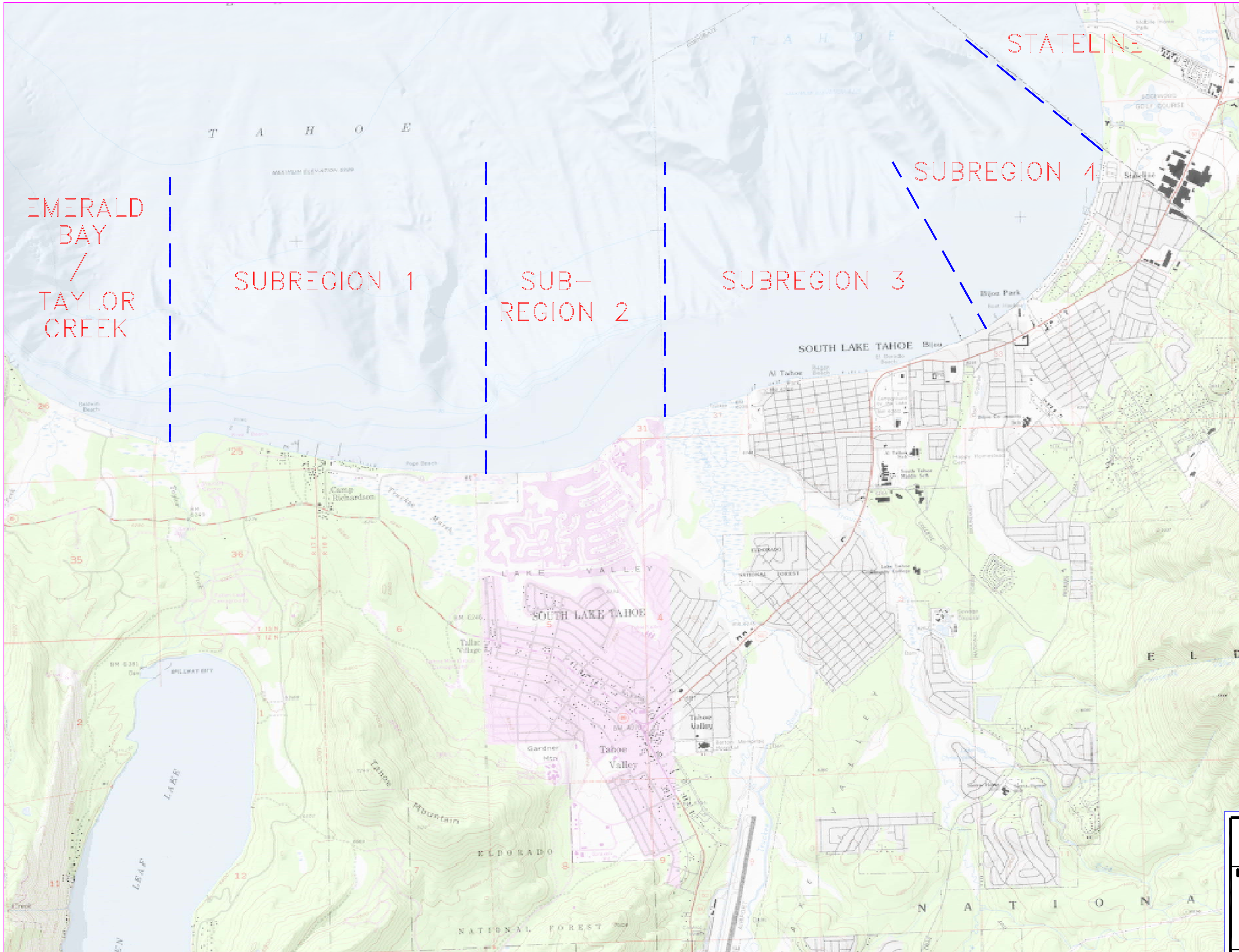
# 4.0 SOUTH LAKE TAHOE/STATELINE NUTRIENT LOADING

## 4.1 Description of Study Area

The aquifer that encompasses South Lake Tahoe, California and Stateline Nevada is, by far, the largest aquifer in the Lake Tahoe Basin. This is also where a majority of the development is located. It is bounded on the east by Emerald Bay and extends just north and west of Stateline Nevada. The watersheds from east to west in this area include Eagle Creek, Cascade Creek, Tallac Creek, Taylor Creek, Camp Richardson, Upper Truckee River, Trout Creek, Bijou Creek, Bijou Park, Edgewood Creek and Burke Creek. The area from Fallen Leaf Lake to the California/Nevada border was numerically modeled because of the extensive data available for this region. During the modeling process, this area was divided into four sub-regions (Fenske 2003). See Figure 4-1 for the delineation of the subregions.

Land development is extensive and consists of a wide variety of land uses. There are single family and multi-family residential neighborhoods intermixed with commercial complexes. Recreational sites such as golf courses, swimming beaches, and parks also abound, as tourism is the main attraction to this area.




DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT,
CORPS OF ENGINEERS
JUNE 2003

LAKE TAHOE | CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA

## SUBREGION DELINEATION

SCALE: NOT TO SCALE | FIGURE: 4-1

C:\DATA\ACAD2000\PROJECTS\M-GALE\TAFXmg09.DWG, 06/12/03, 1:1

### 4.1.1 History of Development

The history presented is based on Lindstrom et al. (2000). Markets created by teamsters traveling through the South Lake Tahoe area in the mid 1850s – 1860s prompted the development of seasonal farming and ranching. As this started, large meadowlands were quickly preempted. By 1860, a pony express route was designated through the area over Echo Summit and Daggett Pass; a post office soon followed. This route was heavily used by passenger and freight wagon traffic en route to the Comstock during the early 1860s.

As shown by the 1870 "California Products of Agriculture" census, hay was a major business in the area in the 1860s. This census shows that 232 metric tons (228 tons) of hay were baled in the region. The 1875 "Resources and Wonders of Tahoe" publication cited that the South Lake Tahoe area was primarily a "hay and dairy producing center, dotted with fertile ranches" and that the ranchers contributed most of the 726 metric tons (800 tons) of hay cut along Tahoe's shoreline in 1875. An estimated 1,800 cows were grazed in the area by 1880, including a pasture on Barton Meadows near the lake shore.

A dairy ranch was in operation in beginning in the late 1920s on a 6 square kilometer (1,600-acre) tract of land on the west side of the Upper Truckee River floodplain in what is now Gardner (Tahoe) Mountain, Tahoe Island Park, Tahoe Keys, and Tamarack Subdivision.

By the 1930s, the Meyers, Al Tahoe, and Bijou subdivisions were thriving, and additional lots were developed at Al Tahoe in the mid 1940s. The 1950s brought the expansion of the gaming industry, which was soon followed by a building boom. This brought on discussions about water and sewage problems as development put more pressure on the existing sewage disposal system. A temporary solution was found by spraying effluent directly onto the land.

Heavenly Valley, a major ski resort, opened in 1956 drawing more tourism into the basin. Soon after, the Squaw Valley Winter Olympics were held, bringing even more attention and visitors to the area. The new subdivision developments of Tahoe Paradise, Golden Bear, and Meadow Lakes were established in the 1960s, and South Lake Tahoe became an incorporated city in 1965. Between 1960 and 1980 Tahoe's population multiplied five times, along with the construction of several major housing developments. The most notable and extensive was the Tahoe Keys subdivision, which required 3 square kilometers (750 acres) of functioning wetland at the mouth of the Upper Truckee River to be dredged and filled.

### 4.1.2 Local Geology

#### Ice Advance into the South Lake Tahoe Basin

Several glacial advances into the South Shore area correspond with those into the Upper Truckee Canyon. Burnett (1971) in mapping the area has identified moraines from these events. The Hobart and Donner glaciations flowed out of Christmas Valley and covered the Meyers area. The ice would have been blocked to the north by Twin Peaks and Tahoe Mountain, and to the west by ice flowing into the Fallen Leaf Lake basin, which eventually resulted in a moraine being deposited between the two ice streams. The result was that ice flowed to the east, around the Twin Peaks and deposited the Airport Moraine, the sedimentary ridge adjacent to the South Lake Tahoe Airport. Burnett has mapped a Tahoe age-end moraine in the Meyers area just north of Tahoe Paradise, while Tioga age moraines have been identified near Meyers Grade. This indicates that Wisconsinan age ice advanced into the Meyers area at least twice.

**Bedrock Geometry**

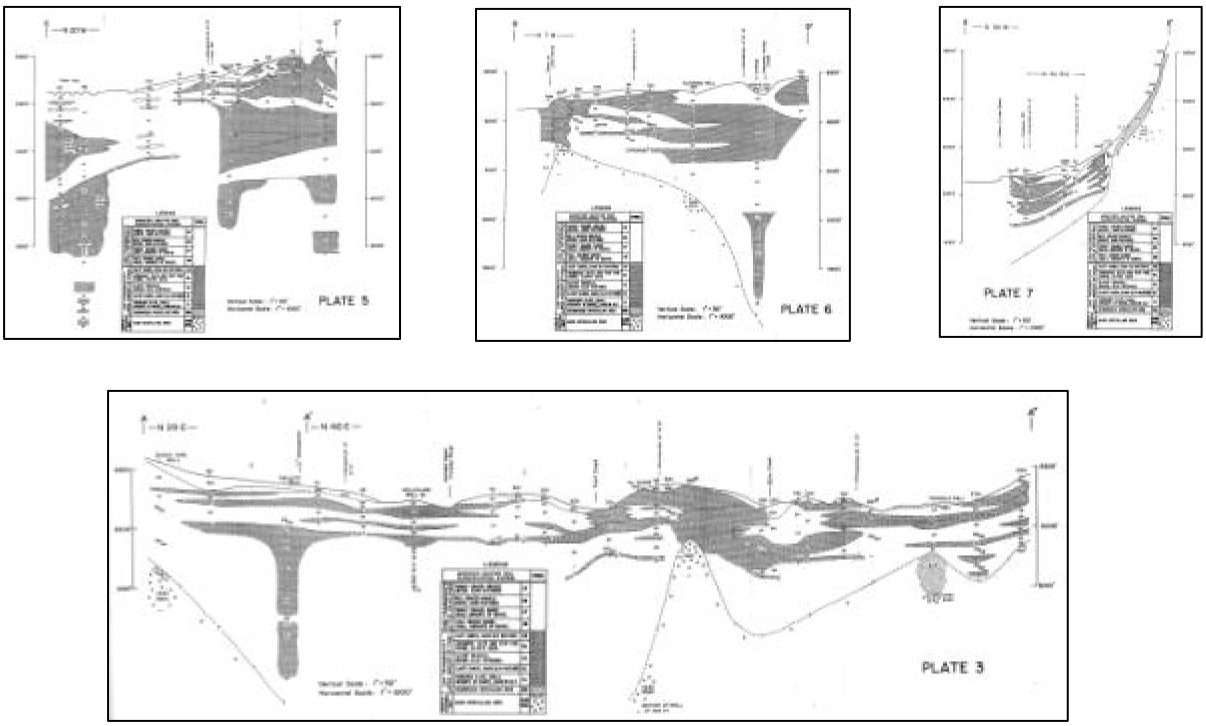
The basin geometry is characterized by two deep subbasins that have been defined using detailed gravity surveys (Appendix A; Blum 1979, Bergsohn 2003). Both of these basins appear to reach depths in excess of 274 meters (900 ft) below the current land surface. One basin is centered below the Meyers area while the other is situated just south of the Tahoe Keys. A low that extends from the South Shore near Bijou towards the Airport probably corresponds to the Stateline Fault that has been mapped just offshore by Kent (2003). Tahoe Mountain and Twin Peaks are situated between these subbasins. A ridge to the west of the Meyers subbasin lies between this subbasin and a basin occupied by Fallen Leaf Lake and is mantled by morainal deposits.

**Hydrogeology of the Meyers and South Lake Tahoe Area**

The hydrologic basin that is occupied by Meyers and South Lake Tahoe is roughly triangular with its apex to the south near Meyers Grade. It extends northward to the south shore of Lake Tahoe where it runs from the west of Camp Richardson to Stateline, NV. The surface topography is generally smooth and gently dipping to the north. Near the lake, surface topography is low lying and poorly drained resulting in the Truckee and Pope marshes. Geologic mapping by Bonham and Burnett (1976) indicates that the surficial deposits are composed of lake and fluvial deposits. East of Twin Peaks, a terraced feature is cored by glacial moraine deposits and flanked by older lake deposits. Twin Peaks and Tahoe Mountain, which project above this depositional surface, are characterized by unweathered and weathered granite.

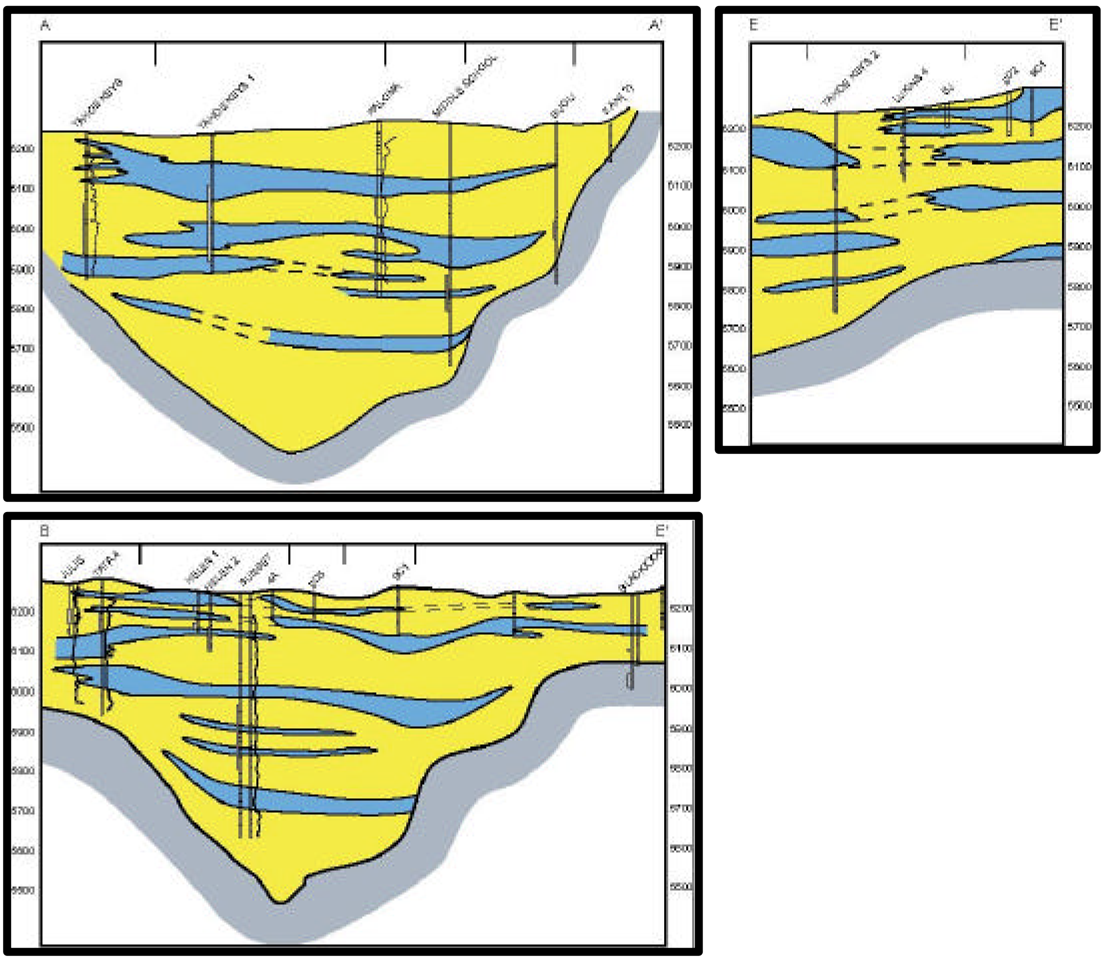
The stratigraphy of the sedimentary fill has been investigated in various phases over the past few decades. The most comprehensive investigation published to date was performed by Scott et al. (1978) in a report for the South Tahoe Public Utility District (STPUD). The investigation was conducted to evaluate potential water reserves for STPUD below South Lake Tahoe. Several of their geologic cross-sections are shown in Figure 4-2. An important feature in these sections is a preponderance of more or less continuous fine-grained units in the upper 30 meters (100 ft). There are several relatively thin units nearer the surface and a thick unit at 18 m (60 ft) to 30 m (100 ft) depth. Cross-sections prepared by Avalex (2002) also show thin, fine-grained units in the upper section and a thicker, more continuous unit at depth. These units dip gently to the north, towards Lake Tahoe.

**Figure 4-2. Geologic cross-sections of the South Lake Tahoe area from Scott et al. (1978). Zones shaded in gray indicate fine-grained units that are hydrologically significant.**



More recently, Einarson (2003) developed a series of geologic cross sections for the South Lake Tahoe and Meyers areas. Due to inconsistent lithologic logging techniques, also previously noted by Scott et al. (1978) who stated "the inconsistent nature of well log descriptions, especially in shallower wells", Einarson utilized borehole geophysical data collected by STPUD in their production wells. Borehole geophysical data represents a nonbiased source of information that can be used for stratigraphic correlation (Keys 1997). Examples of these cross-sections are presented in Figure 4-3. Deflections in the geophysical logs have been used to correlate several thick fine-grained units across the basin as well as other less continuous units. It should be noted that due to the nature of the data used, the fine stringers observed by Scott et al. (1978) and the environmental investigations near the "Y" area of South Lake Tahoe are not identified, but much thicker units have been detected. In his interpretation of these data, Einarson further alludes to these being correlative to the bright reflectors seen offshore by Hyne et al. (1972) and identified as marking the Hobart, Donner and Tahoe glacial events. Regardless of the chronologic interpretation, all of these data indicate that there are several more or less continuous fine-grained units under both South Lake Tahoe and the Meyers area that would impact downward infiltration of groundwater.

**Figure 4-3. Geologic cross-sections derived from borehole geophysical logs by Einarson (2003). Blue indicates fine-grained units while yellow indicates sand and gravel.**



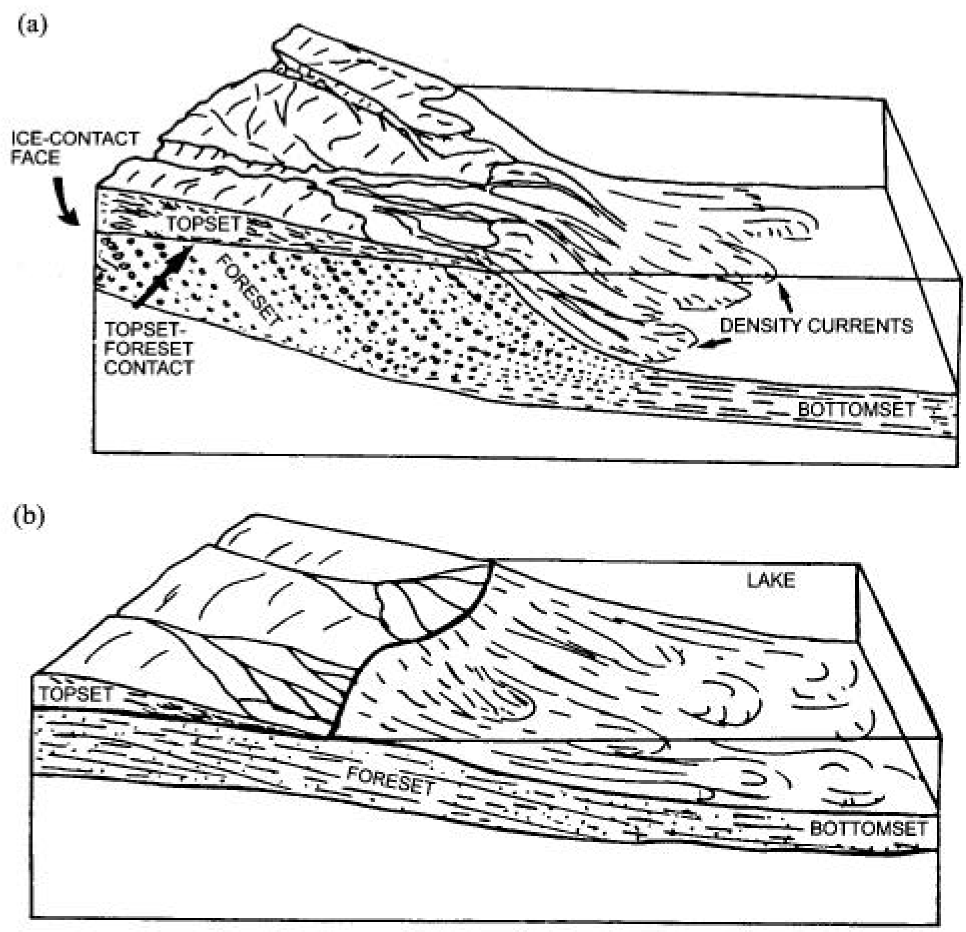
Conceptually, the majority of the deposits comprising the sedimentary fill in the South Lake Tahoe basin would have been deposited in a lacustrine environment. This interpretation is driven largely by the bedrock surface configuration as defined by gravity surveys conducted for STPUD (Blum 1979, Bergsohn 2003). These indicate that the floor of the subbasins below both Meyers and South Lake Tahoe are least 274 m (900 ft) below the land surface. For most of the Quaternary, the minimum lake level was controlled by the sill at Tahoe City near the mouth of the Truckee Canyon (~6220 ft) above mean sea level (m.s.l.). However, at least once, the lake level may have reached about 6220 ft above m.s.l., as is indicated by the submerged shoreline and *in situ* tree stumps (Figure 4-4). However, dating back to the Pliocene, there have also been several high stands, up to at least 7000 ft above m.s.l. During the Quaternary, lake highstands between 18 m (60 ft) and 183 m (600 ft) above the current lake level have been correlated by Birkeland (1962, 1964) to ice damming events during glacial maxima. As a result, even at minimum lake level and compensating for current topography, the basin floor below Meyers was at a bathymetric depth of about 244 m (800 ft) and at least 274 m (900 ft) in South Lake Tahoe near the "Y." Thus, lacustrine processes must account for the majority of the sedimentary fill in both areas. Under these conditions, processes controlling underflow, suspension settling, and surge deposition would have predominated[1].

[1] Underflow: water denser than ambient lake water that flows along the bottom of the lake.
Suspension settling: the process of particles falling through the water column.
Surge deposition: Deposition of sediment that has been re-mobilized by sediment failure processes (e.g., debris flow, turbidite, etc.).

**Figure 4-4. Submerged trees indicating former lower lake levels. From Linstrom et al. (2000).**

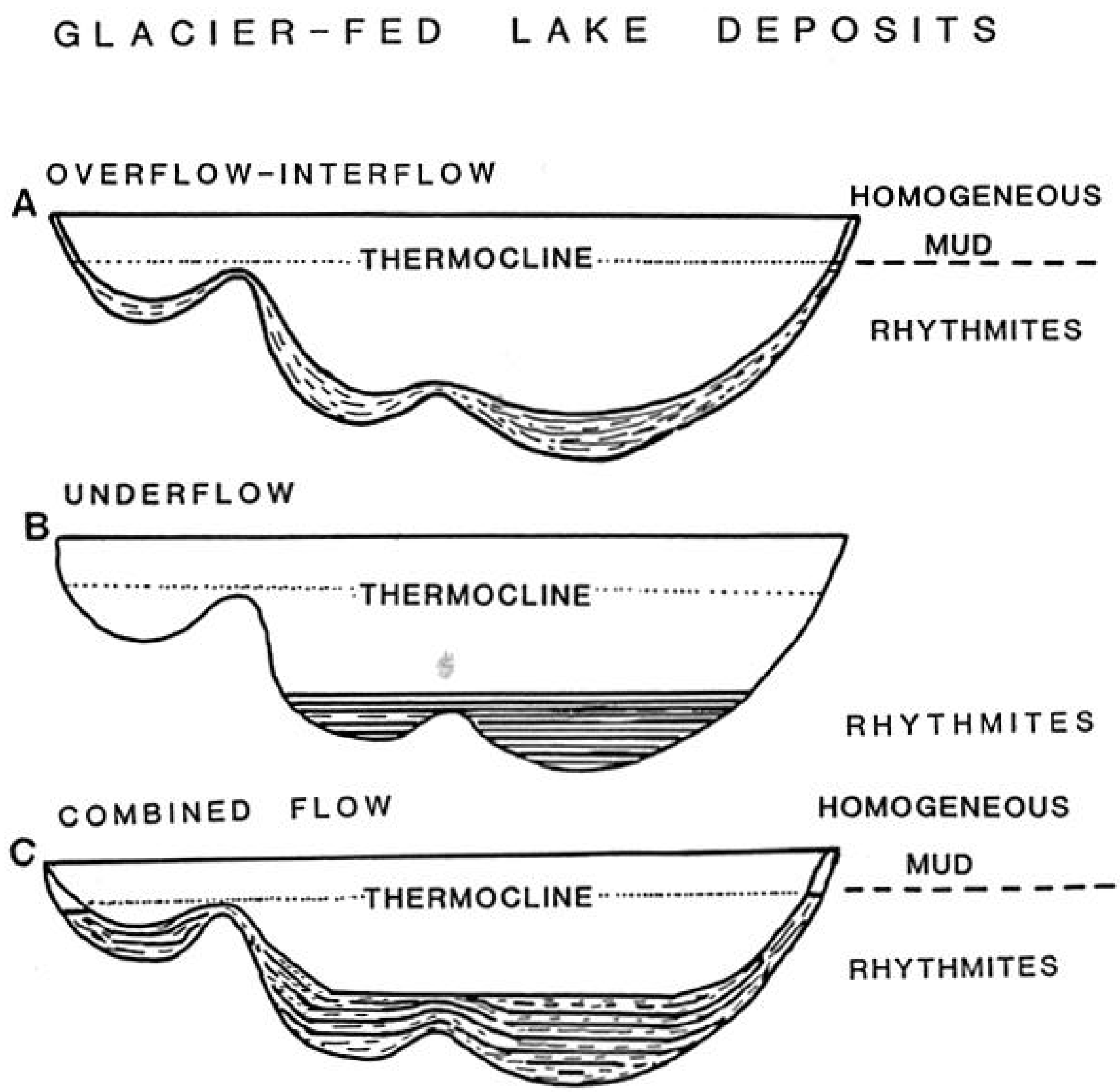
An understanding of the depositional processes aids in determining the geometry of the deposits. For the purpose of this study, two end members of deltaic systems are examined: proximal and distal (Figure 4-5). Deposition in the proximal deltaic environment is characterized by rapid deposition of coarse sediment where streams discharge into the low energy environment of the lake. This deposition results in periodic oversteepening and collapse along the delta front; the collapse produces surge type, density driven, sediment rich flows that transport material downgradient and into the more distal basin (Ashley 2002). Coarser material from the surge-type events is deposited along the cascading face, forming delta foresets, while the finer-grained material is transported into the deeper basin at turbidites and forms bottomsets. As the delta front progrades into the lake through successive deposition of foresets, fluvial deposition in the subaerial environment results in gradual aggradation and the formation of topsets. Such surge deposits would also have been interbedded with underflow and suspension settling deposits, especially in the bottomsets. Deposition in such an environment forms the typical “Gilbert Type” delta.

**Figure 4-5. Ice-contact depositional environments from Ashley (2002). (a) Coarse-grained delta with high-angle foresets deposited in a "proximal" setting. Density underflows can be generated by inflowing meltwater or by foreset slumps. (b) Fine-grained delta, with low angle foresets that can form in the distal portion of an ice-contact delta or where the delta is separated from the ice by an outwash stream.**



The distal deltaic environment is characterized by inflow from streams with a finer grained sediment load. Much of the sediment in such an environment can be transported into the lake in a coherent flow. The dynamics of the flows are dictated by the density stratification of the lake and relative density of the inflow (controlled by water temperature and sediment concentration). Inflow that is denser than the ambient lake water will flow along the lake bottom as an underflow (Ashley 1985). Lighter inflow will form interflows or overflows depending on where they achieve neutral buoyancy in the lake. In the case of underflows, the sediment is transported into the basin and pools in the topographic lows; sedimentation effectively bypasses bathymetric highs (Figure 4-6). Sediment in the overflows and interflows is released through suspension settling, which forms a blanket deposit that thins over highs and thickens in the lows.

**Figure 4-6. Spatial variations in lake-bottom deposits as a function of dispersal mechanisms. (a) overflow-interflow, (b) underflow, and (c) combination overflow-interflow and underflow. From Ashley (1985).**



It must also be realized that there is the potential for significant deposition in front of the Hobart, Donner and Tahoe glaciers, which would have terminated in the lake for significant periods of time. Deposition during these times would have been characterized by proximal subaqueous fans (Rust and Romanelli 1975, Shaw 1985). Deposition in this environment would have dictated rapid accumulation of coarse-grained glaciofluvial sediments where the stream discharged from the ice margin. Debris flows initiated by oversteepening and subsequent collapse, as well as fluctuations in the ice margin, would have distributed coarse material away from the ice margin. Density driven underflows would also have transported sand and silt away from the glacier margin. An important aspect here is that the streams would have discharged at or near the lake floor and would have aggraded as an ice-contact fan. If aggradation was able to progress to lake level, then it would have prograded as a fan-delta. We will ignore further discussion of these complications for this report, understanding that the formation of some of the sand and gravel sequences observed at depth (e.g., Scott et al. 1978, Einarson 2003) were likely deposited in this manner.

During interglacial periods, as well as the early onset and late stages of glaciation, sedimentary processes in the lake would have been dominated by fine-grained deposition. As glaciers were growing and shrinking, sediment loads in the tributary streams would have climbed dramatically (Lawson 1993) resulting in rapid accumulation of silty deposits, especially in basins like that below South Lake Tahoe. In the interglacial periods proper, sedimentation rates would be similar to those of today. Sediment would have been delivered to the lakes in underfit streams with low sediment concentrations. Minor delta progradation may have occurred near the shoreline while suspension settling occurred away from the shore. The result would have been widespread, continuous fine-grained blankets of silt and clay. These deposits would have been thickest over topographic lows and thinning over highs. The blankets also would have pinched towards the basin margin where wave-based activity would have winnowed the fine and coarse sediment introduced from the shore.

Based on this discussion, the stratigraphic sequence below Meyers and South Lake Tahoe is characterized by the interbedding of fine-grained lake sediments with coarse-grained sand and gravel. The fan and delta sedimentation during the glacial period would have prograded through coalescing fans. This can be pictured as a series of stacked sand and gravel lobes, the migration of lobes reflecting changes in sediment delivery through braided outwash channels and distributary channels on the fan in order to fill adjacent lows. The result would be a wedge of coarse-grained material that becomes bracketed by fine-grained units representing “quiet” water conditions. This sequence should repeat itself for each successive glaciation until the depositional surface is subaerially exposed.

**Development of Model Layers**

A six-layer model was developed for conceptualizing the hydrogeology of the South Lake Tahoe and Meyers areas. The goal was to provide relatively high resolution in the upper 46 m (150 ft) and then lump deeper units to behave as a reservoir in the computations. The rationale behind this is that Scott et al. (1978) and Einarson (2003) have demonstrated that thick, continuous fine-grained units exist at depth. These units should impose considerable impedance to vertical flow and therefore restrict flow contaminated by surface processes and anthropogenic inputs to the upper water bearing zones. Therefore, the upper 30 m (100 ft) were subdivided into four units of 8 m (25 ft) thickness. This first layer was used to account for higher groundwater elevations away from the shore. This layer was added that extended from 6243 to 6268 ft above m.s.l. Layers 2 through 6 are the layers which intersect Lake Tahoe, with the upper of these units starting at an elevation of 6243 ft above m.s.l. (the approximate water level at the "Y"). Layer 5 was 15-meter (50-feet) thick and all the remaining sequences were lumped into a deep zone that extends to bedrock. The bedrock configuration was extrapolated from Bergsohn (2003).

Within each of these zones, variations in hydraulic conductivity were estimated based on relative percentages of fines versus coarse sand and gravel. The stratigraphic information used to do this for South Lake Tahoe was extracted from the geologic cross sections in Scott et al. (1978). In the Meyers area, these data were extracted from stratigraphic interpretation based on borehole geophysical logs. The hydrologic conductivity was placed in seven groups for each layer as defined in Table 4-1 and shown in Appendix B (Fenske 2003).

**Table 4-1. Hydrologic Conductivity Estimates (m/day) Initial Values Used**

| | | Conductivity | |
|---|---|---|---|
| Unit | Description | Horizontal | Vertical |
| A | Bedrock | 0.5 | 0.06 |
| B | Clean sand and gravel | 40 | 6 |
| C | Sand and gravel with less than 25% fines | 15 | 0.15 |
| D | Silty Sand | 1.5 | 0.06 |
| E | 25 to 50% fines | 15 | 0.15 |
| F | 50 to 75% fines | 1.5 | 0.006 |
| G | Greater than 75% fines | 0.03 | 0.003 |

Notes:
1. 1 m/day = 3.2808 ft/day

## 4.2 Previous South Lake Tahoe/Stateline Investigations

### 4.2.1 UC Davis Thesis (Woodling 1987)

Woodling conducted a study from January 1986 until February 1987 to characterize the geologic, hydrology, hydraulic and hydrochemical conditions in the South Lake Tahoe groundwater basin. The information was then used to assess the magnitude and distribution of the groundwater and nutrient fluxes to Lake Tahoe. The study area was chosen because there was a large base of available data. In addition to using existing information, Woodling also collected water samples and aquifer tests as part of his fieldwork. Computer simulation was then used to approximate the flow regime.

Woodling determined that a steady-state flow model could approximate the South Lake Tahoe groundwater basin. Although current studies suggest that South Lake Tahoe has a multiple aquifer system, Woodling's study reported that the aquifer was unconfined based on the specific yield and hydrochemical evidence of the distribution of chemical constituents. Woodling determined the transmissivity was highest at the lakeshore near the center of the valley. The concentrations of nitrate-nitrogen in the groundwater were much higher than in the streams or lake. Soluble reactive phosphorous concentrations of groundwater were only slightly higher than in streams and the lake. Woodling's numerical simulation indicated that interflow from the surrounding granitic bedrock is important, and piezometric data suggested that lake water influx to the basin may be possible over a limited area of shoreline.

Woodling determined annual discharge of groundwater to Lake Tahoe in the study area encompassing Trout Creek and Upper Truckee watersheds is $1.7 \times 10^6$ cubic meters (1,375 acre-feet). The nitrate and soluble reactive phosphorus loading from groundwater was 152.6 kg/yr (336.4 lb/yr) and 26.6 kg/yr (58.6 lb/yr), respectively. This accounted for only 4.6 percent and 1.8 percent of the nitrate and soluble reactive phosphorus loads from the watershed, respectively. Woodling also determined that the high nutrient concentrations of groundwater at the sediment-lake interface may be important in the biological processes of Lake Tahoe.

### 4.2.2 UC Davis Institute of Ecology Study (Loeb 1987)

Loeb studied the Upper Truckee and Trout Creek watersheds in the mid 1980s with the objectives of determining the degree of nutrient contamination of the groundwater, quantifying the amount of water and associated nutrients entering Lake Tahoe via groundwater, assessing the impact of groundwater inflow on the growth rate of algae in Lake Tahoe, and outlining mitigation measures to prevent further degradation of groundwater quality.

Groundwater sampling indicated that deeper wells had a much lower nitrate-nitrogen concentration than shallow wells in the Trout Creek watershed. Loeb determined that nitrate enters the aquifer from the land surface and does not mix well into the large reservoir of water deep in the aquifer. In addition, a majority of the highest nitrate concentration wells were near the shore. The range of nitrate-nitrogen concentrations were 0.006 – 2.548 mg/L and 0.023 –

1.528 mg/L for Upper Truckee and Trout Creek, respectively. Loeb found that the overall average nitrate-nitrogen concentration for the wells in the Upper Truckee watershed was 0.466 mg/L while phosphorus was found in low to medium concentrations averaging 0.018 mg/L.

The gradient that Loeb observed in the South Lake Tahoe groundwater basin was 0.0028. Transmissivity was taken from earlier studies and further testing was conducted during his study. Loeb determined the distribution of transmissivity correlated closely with sediment thickness. It was found to be highest near the lake in the vicinity of Tahoe Keys and decreased toward the rock boundaries on the east and west. The average transmissivity was 346 $m^2$/day (3,724 $ft^2$/day).

Loeb observed a large pumping depression near the confluence of Heavenly Valley Creek and Trout Creek extending north into the Al Tahoe area. Loeb considered the possibility of lake water entering the subsurface due to groundwater pumping, but found that it was not conclusive from the groundwater level data alone.

Using the hydraulic data from his study, Loeb determined that the Upper Truckee and Trout Creek watersheds discharged 1.71 x $10^6$ $m^3$/year (1,386 acre-feet/year) of water into Lake Tahoe. Using the nutrient values from the groundwater monitoring network, Loeb estimated groundwater loaded 153 - 799 kg (337 – 1,761 lb) of nitrate-nitrogen per year into Lake Tahoe representing 5 - 20 percent of the total dissolved inorganic nitrogen loading of Lake Tahoe from this area. Annual loading of 27 kg (60 lb) soluble reactive phosphorus was discharged from the South Lake Tahoe watersheds Loeb studied, which represented 2 percent of the watershed's total loading of soluble reactive phosphorus (SRP).

Loeb recommended mitigation measures to deal with the groundwater nutrient loading to Lake Tahoe. He emphasized the need for educating the local community on how to protect the lake, and that fertilizer use should be held to a minimum and sewer systems should be routinely checked for exfiltration points. He also recommended that the water quality agencies require all public and private water systems to grant permission for water quality sampling for environmental health twice a year. Another suggestion was to restrict land disturbance and sustain a monitoring program to evaluate the trends and provide better information.

### 4.2.3 DRI Near Shore Clarity Study (Taylor 2002)

Results from Taylor's monitoring, conducted along the south shore for July 2002, show elevated turbidity near Tahoe Keys, the outlet of the Upper Truckee River and Trout Creek, near Al Tahoe and Bijou Creek. The chlorophyll results are highest near Tahoe Keys and the Upper Truckee River. Moderate concentrations were observed near Bijou Creek.

### 4.2.4 Other Investigations

The USGS maintains the most extensive groundwater monitoring network in the South Lake Tahoe/Stateline area. This is mostly due to the extensive basin and groundwater wells available for monitoring. The South Tahoe Public Utility District operates the largest groundwater municipal supply system in the basin. Groundwater supplies 100 percent of the drinking water for the region. The California Tahoe Conservancy, El Dorado County Department of Transportation and local golf courses also provide localized groundwater monitoring networks. These latter systems are typically built for monitoring water quality rather than public supply of drinking water. El Dorado County Environmental Management, the California DHS and Nevada Bureau of Health Protection Services also retain limited nutrient data relevant to public drinking water standards. The well construction information for regional wells with nutrient monitoring data is provided in Table 4-2.

**Table 4-2. South Lake Tahoe/Stateline Area Well Construction Information**

| Site No. | Elevation ft above msl | Depth of Well meters | (ft) |
|---|---|---|---|
| **Emerald Bay to Taylor Creek** | | | |
| 027 | -- | 114 | (373) |
| 041 | 6235 | 30 | (100) |
| 058 | -- | 14 | (45) |
| 059 | -- | 59 | (195) |
| 066 | -- | 12 | (38) |
| **Subregion 1** | | | |
| 043 | 6235 | -- | -- |
| 055 | 6253.58 | -- | -- |
| 056 | 6240 | 8 | (25) |
| 057 | 6240 | 8 | (25) |
| 053 | 6235 | 7 | (24) |
| 054 | 6235 | 7 | (24) |
| 051 | 6235 | -- | -- |
| 052 | 6235 | -- | -- |
| 047 | 6235 | 11 | (35) |
| 048 | 6235 | 11 | (35) |
| **Subregion 2** | | | |
| 076 | -- | -- | -- |
| 081 | -- | -- | -- |
| 084 | 6280.92 | -- | -- |
| 087 | 6276.89 | 41 | (135) |
| 086 | 6270 | -- | -- |
| 083 | -- | 41 | (135) |
| 085 | 6278 | 79 | (260) |
| 050 | 6230 | 104 | (341) |
| **Subregion 3** | | | |
| 042 | 6255 | 123 | (405) |
| 049 | 6268.33 | -- | -- |
| 039 | 6255.37 | -- | -- |
| 034 | 6250 | -- | -- |
| 044 | -- | 23 | (77) |

| Site No. | Elevation ft above msl | Depth of Well meters | (ft) |
|---|---|---|---|
| 045 | 6260 | 38 | (125) |
| **Subregion 4** | | | |
| 046 | -- | -- | -- |
| 032 | -- | -- | -- |
| 040 | -- | -- | -- |
| 031 | 6235 | 25 | (82) |
| 030 | -- | -- | -- |
| 028 | -- | 32 | (104) |
| 037 | -- | 35 | (115) |
| 024 | -- | -- | -- |
| 025 | -- | -- | -- |
| 026 | 6235 | 43 | (142) |
| 029 | 6250 | 40 | (130) |
| 033 | -- | 46 | (150) |
| 036 | -- | 31 | (102) |
| 038 | -- | 30 | (98) |
| 035 | -- | 34 | (110) |
| 023 | -- | -- | -- |
| 021 | -- | 25 | (82) |
| 013 | 6239.48 | 55 | (180) |
| 022 | -- | -- | -- |
| 014 | 6237.88 | -- | -- |
| 020 | -- | 21 | (70) |
| 011 | 6240 | 76 | (250) |
| 016 | 6230 | 76 | (248) |
| 019 | 6260 | -- | -- |
| 018 | -- | -- | -- |
| 005 | -- | -- | -- |
| 008 | -- | 30 | (100) |
| 015 | -- | -- | -- |
| 006 | -- | 23 | (76) |
| 009 | -- | 21 | (70) |
| 010 | -- | -- | -- |
| 007 | -- | -- | -- |
| 012 | -- | -- | -- |
| **Stateline** | | | |
| 197 | 6235 | 18 | (58) |
| 200 | 6230 | 3 | (9) |
| 199 | 6230 | 3 | (11) |
| 201 | 6230 | 3 | (9) |
| 003 | 6230 | 2 | (6) |
| 202 | 6240 | 4 | (13) |

| Site No. | Elevation ft above msl | Depth of Well meters | (ft) |
|---|---|---|---|
| 001 | 6235 | 2 | (8) |
| 002 | 6235 | 3 | (10) |
| 004 | 6245 | 7 | (23) |
| 188 | 6275 | 61 | (200) |
| 193 | 6260 | 8 | (25) |
| 198 | 6360 | 5 | (18) |
| 186 | 6320 | 2 | (8) |
| 219 | 6335 | -- | -- |

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, LRWQC, CTC, TRPA, El Dorado EM, STPUD, Nevada BHPS, California DHS, California DWR, and Nevada DWR.

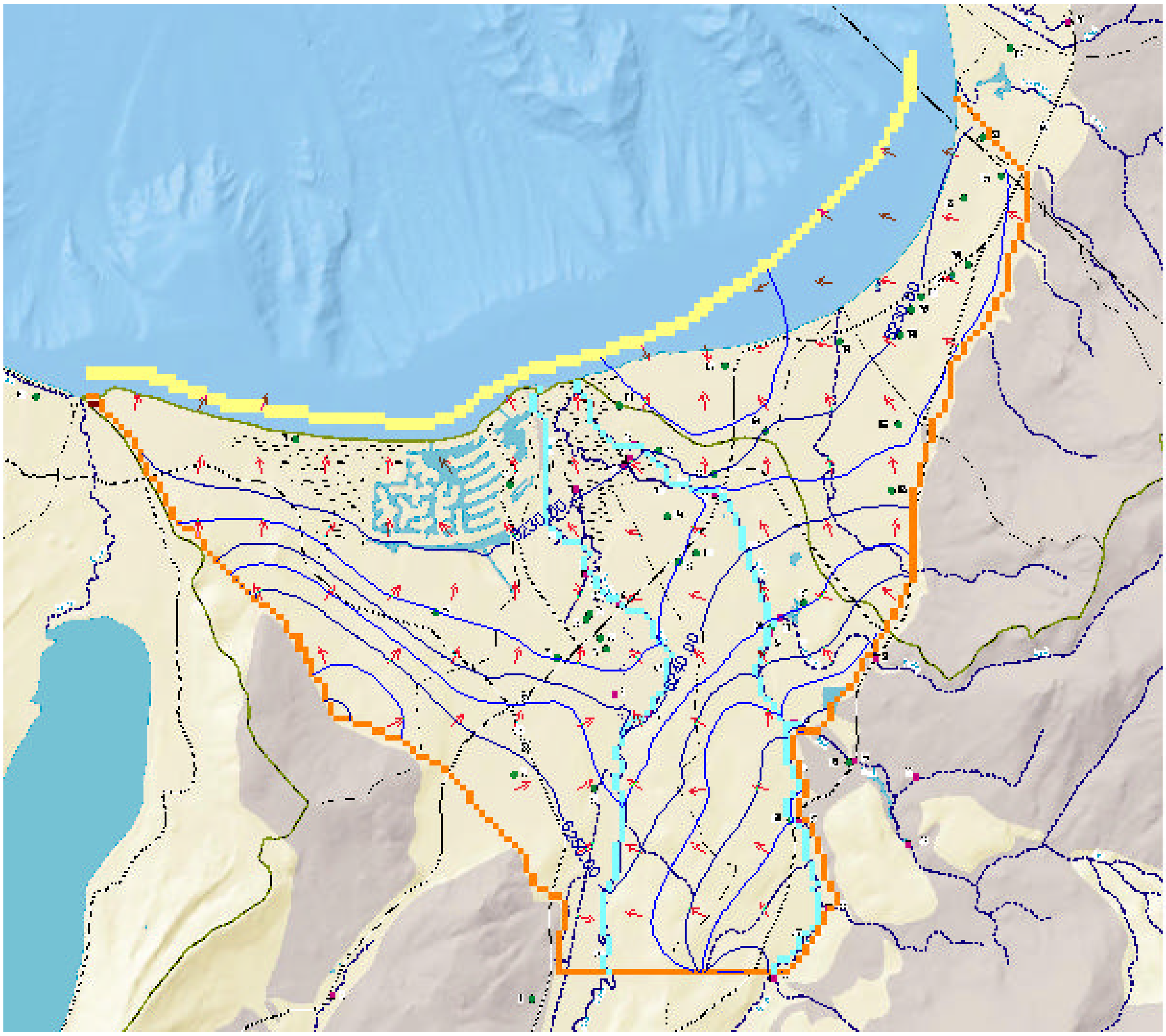
Monitoring data available from agencies date back to 1980. Monitoring of some wells still continues as part of the USGS basin-wide monitoring network and local groundwater monitoring networks. This data is collected to monitor both environmental and public health. See Section 4.3 for a detailed description of the nutrient data.

Groundwater elevations have been recorded periodically as well. These elevations were used in the numerical model for calibration in addition to stream gage elevation data. See Appendix B for a comprehensive report of the groundwater modeling effort.

## 4.3 Nutrient Concentrations

Groundwater wells are spread throughout the area from Christmas Valley to the Lake shore. The groundwater that is likely to discharge directly to the lake is within 1,500 meters (4,921 ft) of the shoreline. Additionally, groundwater located within 2,000 meters (6,562 ft) directly south of the Tahoe Keys is likely to discharge into the Keys and subsequently into Lake Tahoe. Figure 4-7 shows the flow lines and groundwater contours in the model area. To the south and east of Tahoe Keys, the groundwater tends to travel towards the Upper Truckee River and Trout Creek (Fenske 2003). Because of the extensive monitoring system, this discussion will focus on the wells within the area where groundwater likely discharges directly to the Lake.

**Figure 4-7. South Lake Tahoe Model Area Groundwater Contours and Flow Lines**



Notes:

1. Figure obtained from Fenske (2003)

LRWQCB requires groundwater monitoring at Bijou golf course to establish baseline conditions in early spring, monitor the effects of chemicals applied during the summer season and determine the residual effects once the active season has ceased. LRWQCB also requires the golf course to build a database adequate to provide effective feedback for golf course chemical and irrigation management with respect to environmental protection (LRWQCB 2000b). To build the database, LRWQCB has required that groundwater be monitored on a monthly basis. The golf course is required to sample groundwater for dissolved chemical constituents passing through a 0.45 micron filter. The nutrient constituents requiring analysis are dissolved Kjeldahl Nitrogen, dissolved nitrite plus nitrate, and dissolved orthophosphorus and total dissolved phosphorus. TRPA also requires Edgewood Golf Course to collect groundwater samples. Edgewood golf course is required to sample groundwater quality to assure that the fertilizer management plan will meet the water quality thresholds. The sample testing focuses on nutrients representative of types of fertilizers used on the property. Three groundwater sites are monitored on a monthly basis, and the samples are tested for nitrate plus nitrite, ammonia, and total phosphorus.

USGS has been collecting samples periodically for many years. These wells are sampled as part of a Tahoe basin-wide monitoring program. The USGS typically tests for dissolved ammonia, dissolved Kjeldahl nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus, and total dissolved phosphorus. The specific analytical profiles per well may vary.

The California DHS, Nevada BHPS, STPUD and El Dorado County EM require sampling for nitrate and nitrite in drinking water wells. These samples have been added to the larger data set to combine as much nutrient chemistry collected in the basin as possible.

The average concentrations and top of open interval for wells located near the lake are included in Table 4-3 through Table 4-8. The top of open interval represents the depth below ground surface that groundwater can freely enter the well (e.g. top of screen or bottom of casing in fractured rock). The well locations and land use in each are shown in Figure 4-8 through Figure 4-13.

### 4.3.1 Emerald Bay to Taylor Creek Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-8. Well 041 is the only well that has been monitored for all applicable forms of dissolved nitrogen and phosphorus. Well 041 has been sampled since 1995. Wells 027, 058, 059 and 066 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite testing.

The dissolved ammonia + organic nitrogen concentrations for well 041 range from 0.001 mg/L to 0.09 mg/L, averaging 0.045 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.034 mg/L to 0.064 mg/L with an average of 0.051 mg/L. This results in an average total dissolved nitrogen concentration of 0.096 mg/L. The average total nitrate concentrations found in wells 027, 058, 059 and 066 range from 0.012 mg/L to 0.4584 mg/L. Lower concentrations of nitrogen are found in well 041. This may be indicative of denitrification, which occurs as the groundwater travels towards the lake, or the difference in dissolved versus total nitrogen concentrations. Table 4-3 includes the dissolved nitrogen concentrations for well 041.

Orthophosphorus concentrations for well 041 range from 0.022 mg/L to 0.085 mg/L, averaging 0.071 mg/L. The range of total dissolved phosphorus is 0.06 mg/L to 0.101 mg/L, averaging 0.085 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-3 includes the dissolved phosphorus concentrations for well 041.

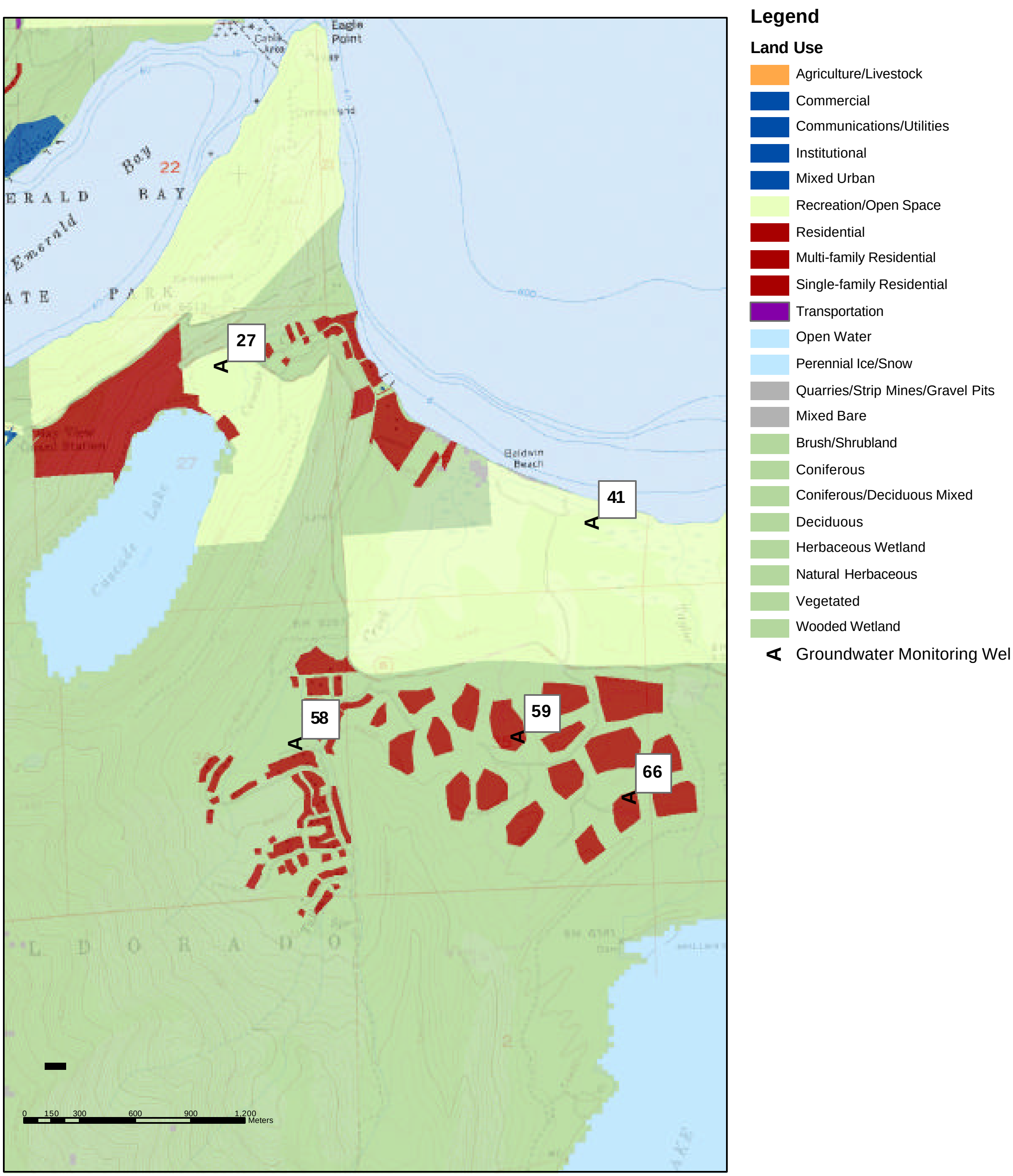
Well 041 is well placed to represent the downgradient conditions for the area. It is likely an accurate reflection of the majority of the groundwater discharging across this area (Figure 4-8).

**Table 4-3. Emerald Bay to Taylor Creek Average Nutrient Concentrations (mg/L)**

| | Well ID |
|---|---|
| Constituent | 041 |
| Ammonia + Organic | 0.045 |
| Nitrate | 0.051 |
| Total Nitrogen | 0.096 |
| Orthophosphorus | 0.071 |
| Total Phosphorus | 0.085 |
| Top of Open Interval (ft bgs) | 70 |

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS.
3. Top of Open Interval with a -- indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

**Figure 4-8. Emerald Bay to Taylor Creek Groundwater Wells and Land Use**




Notes:

1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

### 4.3.2 Subregion 1 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-9. Wells 043, 047, 048 and 051 - 057 have been monitored for all forms of dissolved nitrogen and phosphorus that are of concern as part of this evaluation.

The dissolved ammonia + organic nitrogen concentrations range from 0.01 mg/L to 2.8 mg/L, averaging 0.26 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.002 mg/L to 0.108 mg/L with an average of 0.031 mg/L. This results in an average total dissolved nitrogen concentration of 0.289 mg/L. Table 4-4 includes the dissolved nitrogen concentrations for wells in subregion 1.

Orthophosphorus concentrations in subregion 1 range from 0.001 mg/L to 0.051 mg/L, averaging 0.025 mg/L. The range of total dissolved phosphorus is 0.012 mg/L to 0.098 mg/L, averaging 0.035 mg/L. Table 4-4 includes the dissolved phosphorus concentrations for wells in subregion 1.

Wells 043, 047 and 048 are considered the downgradient wells in subregion 1. They are well placed to represent the downgradient conditions for the area. The data shows that the concentrations of nutrients are higher in the downgradient wells versus the upgradient wells. The predominant land use in this area is recreational (Camp Richardson) (Figure 4-9). Large numbers of geese that are typically present in this area could contribute to the increased nutrient concentrations. Because all of the wells in this area are shallow, they likely represent the highest nutrient concentrations in this area.

**Table 4-4. South Lake Tahoe Subregion 1 Average Nutrient Concentrations (mg/L)**

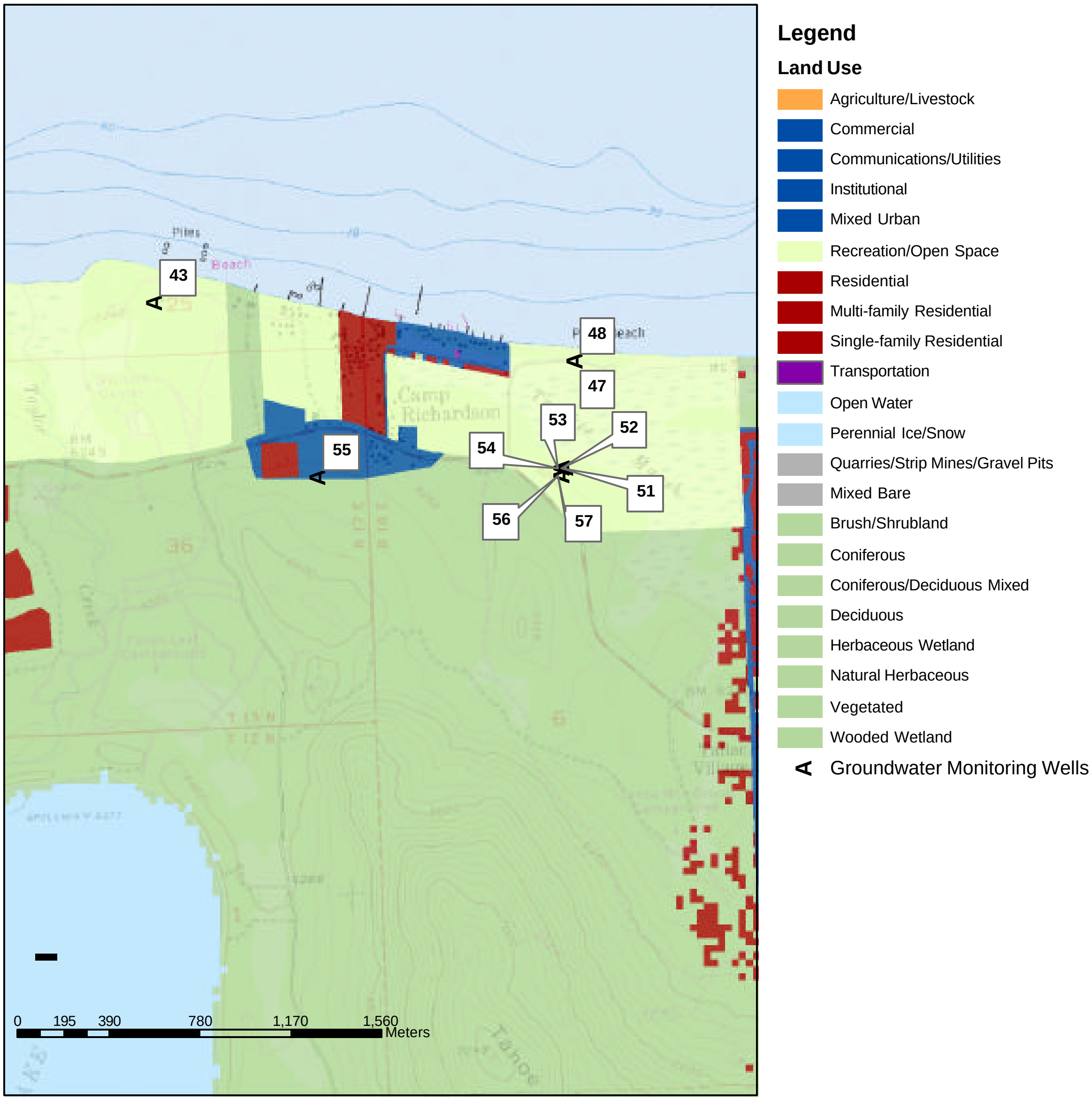
| | Well ID | | | | |
|---|---|---|---|---|---|
| Constituent | 055 | 056 | 057 | 051 | 052 |
| Ammonia + Organic | na | 0.01 | 0.02 | 0.07 | 0.01 |
| Nitrate | 0.058 | 0.023 | 0.005 | 0.028 | 0.02 |
| Total Nitrogen | -- | 0.033 | 0.025 | 0.098 | 0.03 |
| Orthophosphorus | 0.1 | 0.015 | 0.003 | 0.017 | 0.005 |
| Total Phosphorus | na | 0.034 | 0.018 | 0.043 | 0.019 |
| Top of Open Interval (ft bgs) | -- | 10.25 | 3.7 | 8.28 | 5.15 |

| | Well ID | | | | |
|---|---|---|---|---|---|
| Constituent | 053 | 054 | 047 | 048 | 043 |
| Ammonia + Organic | 0.05 | 0.04 | 1.4218 | 0.64 | 0.08 |
| Nitrate | 0.007 | 0.002 | 0.0678 | 0.038 | 0.064 |
| Total Nitrogen | 0.057 | 0.042 | 1.4896 | 0.678 | 0.144 |
| Orthophosphorus | 0.011 | 0.003 | 0.0337 | 0.031 | 0.0325 |
| Total Phosphorus | 0.025 | 0.012 | 0.0502 | 0.046 | 0.0693 |
| Top of Open Interval (ft bgs) | 17 | 3.4 | 15.45 | 5 | -- |

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS and STPUD.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

**Figure 4-9. South Lake Tahoe Subregion 1 Groundwater Wells and Land Use**




Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

### 4.3.3 Subregion 2 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-10. Well 050 has been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-5 have only been sampled for dissolved nitrate and total dissolved phosphorus. Wells 076, 081 and 083 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for well 050 range from 0.001 mg/L to 0.2 mg/L, averaging 0.043 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-5, which include nitrite, range from 0.01 mg/L to 2.36 mg/L with an average of 0.678 mg/L. Well 050 has an average total dissolved nitrogen concentration of 0.418 mg/L. The average total nitrate concentrations found in wells 076, 081 and 083 range from 0.415 mg/L to 1.01 mg/L. Table 4-5 includes the dissolved nitrogen concentrations for wells 050, and 084 - 087.

Orthophosphorus concentrations for well 050 range from 0.015 mg/L to 0.02 mg/L, averaging 0.018 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-5 is 0.01 mg/L to 0.78 mg/L, averaging 0.039 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-5 includes the dissolved phosphorus concentrations for wells 050, and 084 - 087.

The distribution of wells in the area is not suited to characterize the area (Figure 4-10). The downgradient well, 050, would not detect nutrients migrating from the residential neighborhoods to the southwest. There is a noticeable difference in nitrogen concentrations between the deep wells and those in the upper aquifer. The phosphorus concentrations do not vary much downgradient or from upper to lower aquifer. The distribution of nitrogen concentrations in this area seems to be related to nearby sources, and an assessment of cumulative sources is not possible as there are no wells suited to make this assessment. The upgradient cluster of wells located within a residential land use only (wells 084 – 087) does not seem to have a defined trend in nitrate concentrations in the downgradient direction.

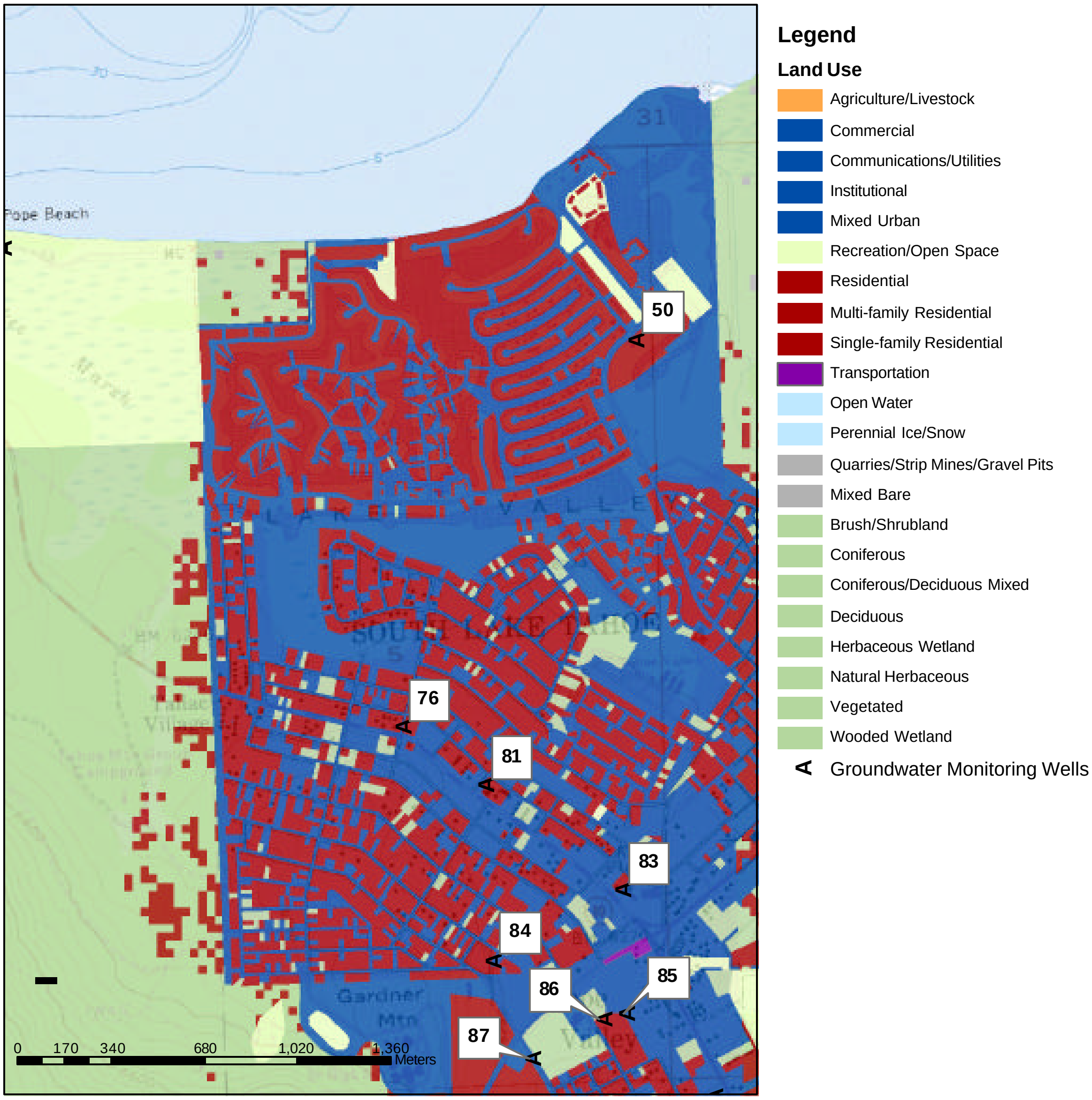
**Table 4-5. South Lake Tahoe Subregion 2 Average Nutrient Concentration (mg/L)**

| | Well ID | | | | |
|---|---|---|---|---|---|
| Constituent | 084 | 087 | 085 | 086 | 050 |
| Ammonia + Organic | na | na | na | na | 0.043 |
| Nitrate | 0.719 | 1.017 | 0.029 | 1.252 | 0.375 |
| Total Nitrogen | -- | -- | -- | -- | 0.418 |
| Orthophosphorus | na | na | na | na | 0.018 |
| Total Phosphorus | 0.027 | 0.077 | 0.024 | 0.037 | 0.029 |
| Top of Open Interval (ft bgs) | 40 | 65 | 190 | 87 | <341 |

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, and STPUD.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

**Figure 4-10. South Lake Tahoe Subregion 2 Groundwater Wells and Land Use**




Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

### 4.3.4 Subregion 3 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-11. Wells 045 and 049 have been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-6 have only been sampled for dissolved nitrate and total dissolved phosphorus. Wells 034 and 044 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for wells 045 and 049 range from 0.01 mg/L to 0.2 mg/L, averaging 0.124 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-6, which include nitrite, range from 0.01 mg/L to 1.31 mg/L with an average of 0.346 mg/L. Wells 045 and 049 have an average total dissolved nitrogen concentration of 0.396 mg/L. The average total nitrate concentrations found in wells 034 and 044 are 1.276 mg/L and 3.614 mg/L, respectively. Table 4-6 includes the dissolved nitrogen concentrations for wells 039, 042, 045 and 049.

Orthophosphorus concentrations for wells 049 and 045 range from 0.01 mg/L to 0.04 mg/L, averaging 0.021 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-6 is 0.012 mg/L to 0.7 mg/L, averaging 0.033 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-6 includes the dissolved phosphorus concentrations for wells 039, 042, 045 and 049.

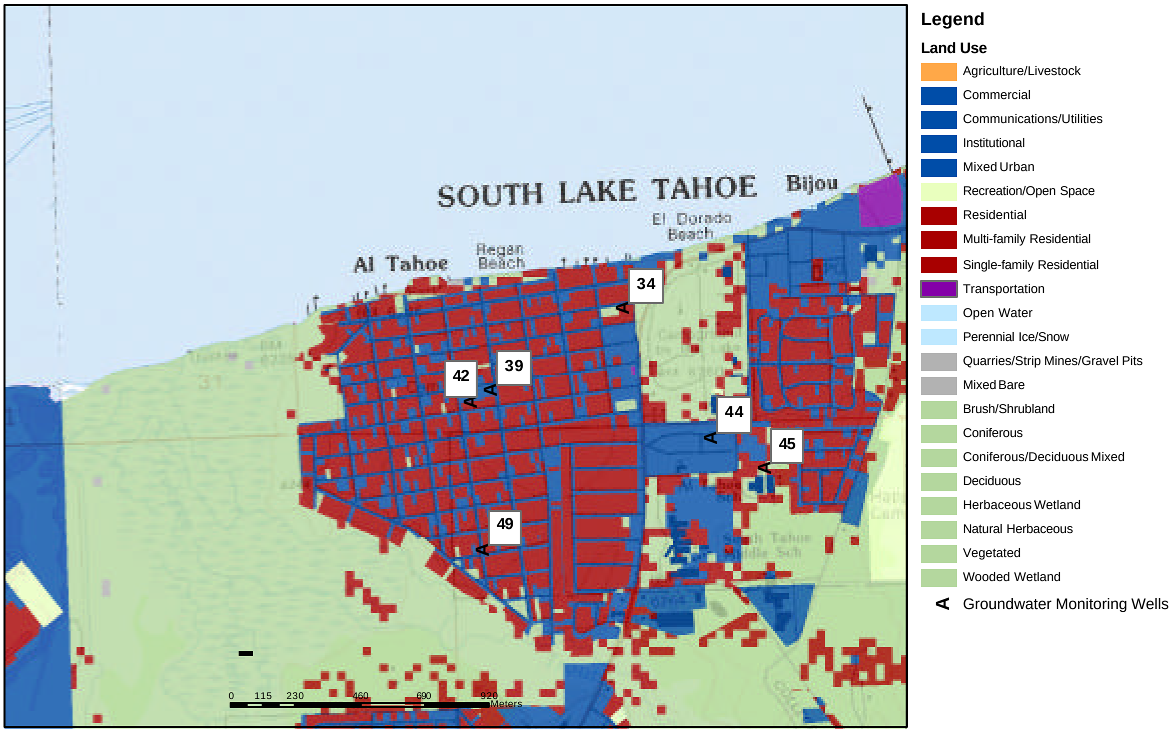
The high total nitrate concentrations found in well 044 could be due to groundwater migrating towards the pumping wells from the vicinity of the golf course and residential neighborhood. Unlike the nutrient concentrations found in subregion 2, the higher nitrogen concentrations are found in the deeper aquifer in this region. Phosphorus concentrations do not vary much with depth. This may be due to the fact that wells 042 and 039 are municipal supply wells used by STPUD. Wells 042 and 039 are STPUD's two primary wells municipal supply for the area. As shown by the groundwater flow model, the pumping forms a significant cone of depression (Fenske 2003). These wells may be drawing the groundwater, along with the nutrients, towards the wells.

**Table 4-6. South Lake Tahoe Subregion 3 Average Nutrient Concentration (mg/L)**

| | Well ID | | | |
|---|---|---|---|---|
| Constituent | 049 | 042 | 039 | 045 |
| Ammonia + Organic | 0.2 | na | na | 0.0476 |
| Nitrate | 0.1553 | 0.2879 | 0.5499 | 0.3894 |
| Total Nitrogen | 0.3553 | -- | -- | 0.437 |
| Orthophosphorus | 0.028 | na | na | 0.014 |
| Total Phosphorus | 0.028 | 0.0378 | 0.0387 | 0.0294 |
| Top of Open Interval (ft bgs) | 268 | 170 | 180 | 86 |

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS, STPUD, and El Dorado EM.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

**Figure 4-11. South Lake Tahoe Subregion 3 Groundwater Wells and Land Use**




Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

### 4.3.5 Subregion 4 Nutrient Concentrations

The wells and land use in subregion 4 are depicted in Figure 4-12. Wells 024 - 026, 031, 032, 040, and 046 have been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-7 have only been sampled for dissolved nitrate and total dissolved phosphorus. All other wells shown on Figure 4-12 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for wells 024 - 026, 031, 032, 040, and 046 range from 0.01 mg/L to 4.8 mg/L, averaging 0.535 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-7, which include nitrite, range from 0.01 mg/L to 10 mg/L with an average of 0.747 mg/L. The average total dissolved nitrogen for wells 024 - 026, 031, 032, 040, and 046 ranges from 0.292 mg/L to 5.294 mg/L, averaging 1.508 mg/L. The total nitrate concentrations range from are 0.009 mg/L and 3.613 mg/L, averaging 0.345 mg/L. Table 4-7 includes the dissolved nitrogen concentrations for wells 024 - 026, 031, 032, 040, and 046.

Orthophosphorus concentrations for wells 024 - 026, 031, 032, 040, and 046 range from 0.006 mg/L to 4.1 mg/L, averaging 0.119 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-6 is 0.006 mg/L to 0.97 mg/L, averaging 0.052 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-7 includes the dissolved phosphorus concentrations for wells 024 - 026, 031, 032, 040, and 046.

Again, subregion 4 shows high levels of nitrogen in both the shallow and deep aquifers and a slight difference in the phosphorus concentrations (Table 4-7). A majority of the wells located within the subregion are designed to measure groundwater quality from specific sources. These areas do show an increased nutrient concentration related to those sources. The most notable is well 046 which is located within the Bijou golf course.

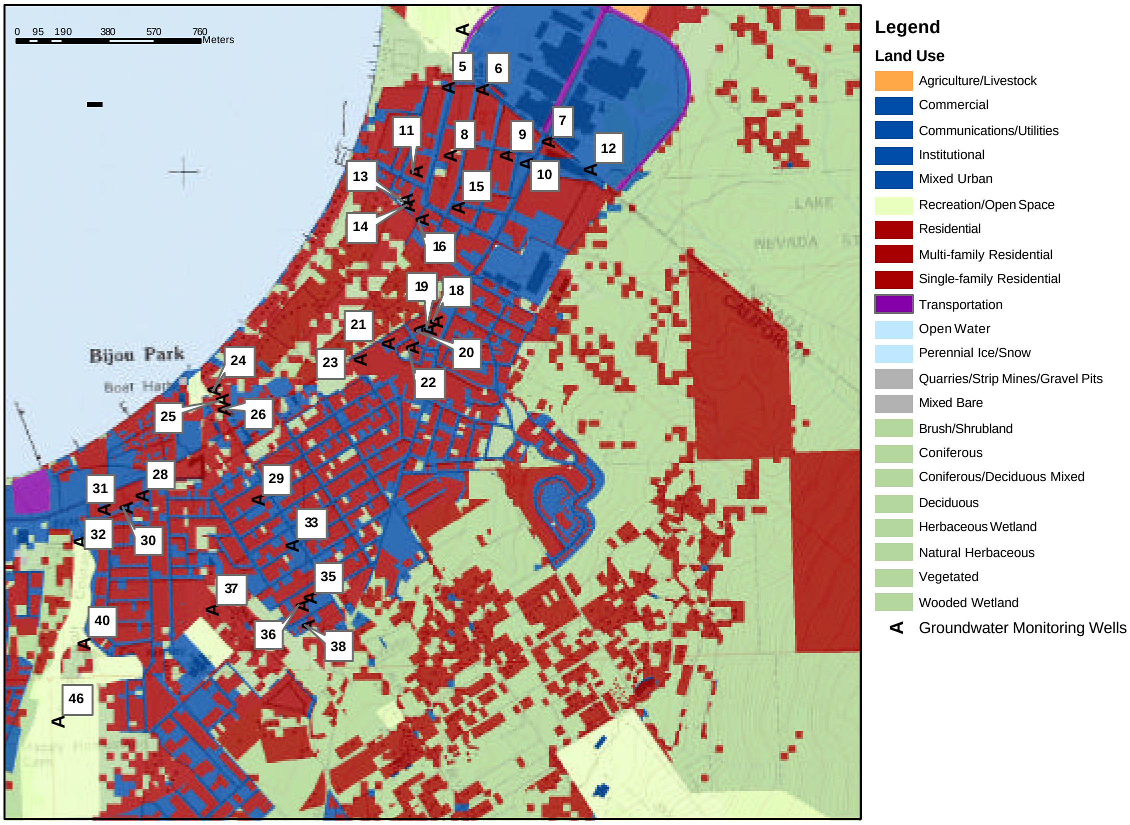
**Table 4-7. South Lake Tahoe Subregion 4 Average Nutrient Concentration (mg/L)**

| | Well ID | | | | | |
|---|---|---|---|---|---|---|
| Constituent | 031 | 026 | 013 | 014 | 016 | 046 |
| Ammonia + Organic | 0.0636 | 0.2 | na | na | na | 0.2736 |
| Nitrate | 0.7784 | 0.092 | 0.4837 | 0.0816 | 0.2911 | 5.02 |
| Total Nitrogen | 0.842 | 0.292 | -- | -- | -- | 5.2936 |
| Orthophosphorus | 0.0207 | 0.006 | na | na | na | 0.029 |
| Total Phosphorus | 0.0354 | 0.006 | 0.0178 | 0.0134 | 0.01 | 0.0313 |
| Top of Open Interval (ft bgs) | 50 | <142 | 168 | 169 | 181 | Shallow |
| | Well ID | | | | | |
| Constituent | 032 | 040 | 007 | 012 | 024 | 025 |
| Ammonia + Organic | 0.2614 | 0.54 | na | na | 0.6538 | 1.7545 |
| Nitrate | 0.5135 | 0.38 | 1.2518 | 0.0448 | 0.0138 | 0.0136 |
| Total Nitrogen | 0.7749 | 0.92 | -- | -- | 0.6676 | 1.7681 |
| Orthophosphorus | 0.5188 | 0.026 | na | na | na | na |
| Total Phosphorus | 0.0542 | 0.021 | na | na | 0.2026 | 0.1318 |
| Top of Open Interval (ft bgs) | Shallow | Shallow | Shallow | Shallow | Shallow | Shallow |

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, LRWQCB, STPUD, El Dorado EM.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

## Figure 4-12. South Lake Tahoe Subregion 4 Groundwater Wells and Land Use




Notes:

1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

### 4.3.6 Stateline Nutrient Concentrations

The wells and land use in the Stateline area are depicted in Figure 4-13. All wells included in Table 4-8 have been monitored for all forms of the dissolved nutrients of interest to this evaluation.

The dissolved ammonia + organic nitrogen concentrations for Stateline wells range from 0.01 mg/L to 1.1 mg/L, averaging 0.365 mg/L. The dissolved nitrate concentrations for Stateline wells, which include nitrite, range from 0.001 mg/L to 16.3 mg/L with an average of 0.972 mg/L. The average total dissolved nitrogen for Stateline wells ranges from 0.127 mg/L to 8.88 mg/L, averaging 1.337 mg/L. Table 4-8 includes the dissolved nitrogen concentrations for Stateline wells.

Orthophosphorus concentrations for Stateline wells range from 0.001 mg/L to 0.049 mg/L, averaging 0.015 mg/L. The range of total dissolved phosphorus for Stateline wells is 0.005 mg/L to 0.069 mg/L, averaging 0.023 mg/L. Table 4-8 includes the dissolved phosphorus concentrations for Stateline wells.

The Stateline area wells demonstrate a difference between the deep and shallow groundwater nutrient concentrations. The nitrogen concentrations in the golf course increase downgradient, indicating that the golf course is acting as a source of additional nutrients to the groundwater. The area in the northern portion of the golf course shows significant detections of nitrogen. This is likely due to not only the golf course, but also the upgradient residential land use (Figure 4-13). Wells 198 - 202 are interesting to observe. The upgradient well, 198 is located within a residential area and shows high concentrations of nitrogen. The concentration decreases downgradient and then slightly increases again, showing that the more significant source of nitrogen is in the residential area as opposed to the open area closer to the lake. The phosphorus shows a consistent increase in concentration as the groundwater progresses towards the lake. The residential area does not prove to be a significant contributor of phosphorus, rather there seems to be a natural increase in phosphorus as it passes through the open area near the lake.

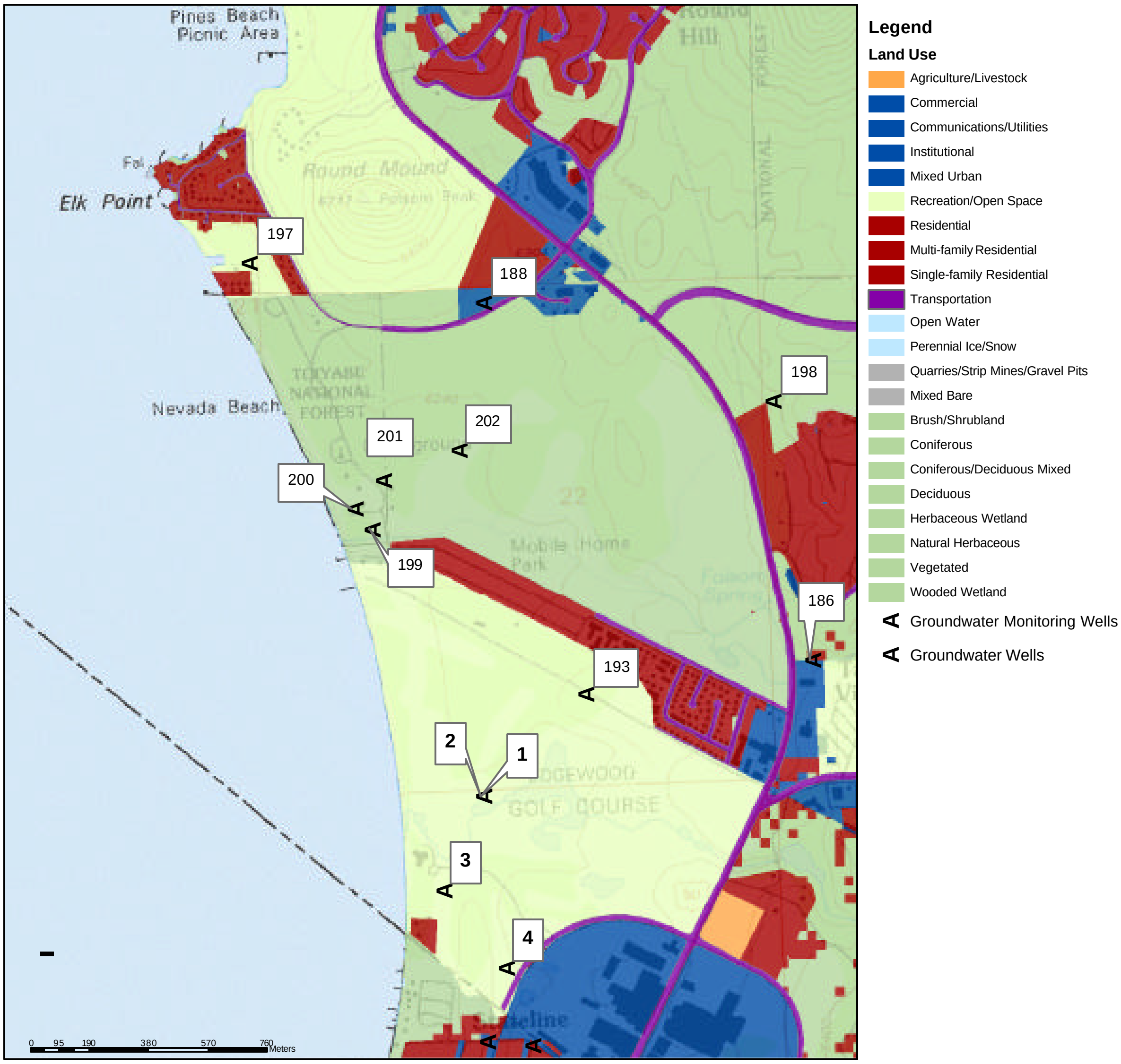
**Table 4-8. Stateline Average Nutrient Concentration (mg/L)**

| Constituent | Well ID 004 | 003 | 001 | 002 | 198 |
|---|---|---|---|---|---|
| Ammonia + Organic | 0.12 | 1.1 | 0.14 | 0.3 | 0.45 |
| Nitrate | 0.0069 | 0.01 | 1.402 | 2.8 | 0.055 |
| Total Nitrogen | 0.1269 | 1.11 | 1.542 | 3.1 | 0.505 |
| Orthophosphorus | 0.0141 | 0.024 | 0.003 | 0.005 | 0.006 |
| Total Phosphorus | 0.0321 | 0.033 | 0.0075 | 0.005 | 0.0135 |
| Top of Open Interval (ft bgs) | <23 | <6 | <8 | <10 | <18 |
| **Constituent** | **Well ID 193** | **186** | **219** | **199** | **200** |
| Ammonia + Organic | 0.2147 | 0.6 | 0.04 | 0.6 | 0.8 |
| Nitrate | 8.6659 | 0.01 | 0.143 | 0.08 | 0.01 |
| Total Nitrogen | 8.8806 | 0.61 | 0.183 | 0.68 | 0.81 |
| Orthophosphorus | 0.0092 | 0.049 | 0.015 | 0.012 | 0.037 |
| Total Phosphorus | 0.0241 | 0.054 | 0.017 | 0.016 | 0.065 |
| Top of Open Interval (ft bgs) | <25 | <8 | 0 | <11 | <9 |
| **Constituent** | **Well ID 201** | **202** | **188** | **197** | |
| Ammonia + Organic | 0.4 | 0.2 | 0.0735 | 0.0694 | |
| Nitrate | 0.01 | 0.01 | 0.0631 | 0.34 | |
| Total Nitrogen | 0.41 | 0.21 | 0.1366 | 0.4094 | |
| Orthophosphorus | 0.008 | 0.007 | 0.009 | 0.0078 | |
| Total Phosphorus | 0.005 | 0.01 | 0.0238 | 0.0227 | |
| Top of Open Interval (ft bgs) | <9 | <13 | <200 | <58 | |

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

# Figure 4-13. Stateline Groundwater Wells and Land Use



## 4.4 Groundwater Discharge

A groundwater flow model was developed by the USACE Hydrologic Engineering Center. The model was broken down into four areas based upon discharge estimates (Fenske 2003). Several different scenarios were modeled to show the change in discharge based upon climatic changes. The values used in this report are the normal average year, average spring and average fall. Modeling was also conducted to show a dry and wet year. See Appendix B for a more detailed discussion.

Table 4-9, Table 4-10, and Table 4-11 depict the total groundwater discharge rates for each area. Figure 4-14, Figure 4-15, and Figure 4-16 depict the total groundwater discharge rates in for each area.

**Table 4-9. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Normal Year (Fenske 2003)**

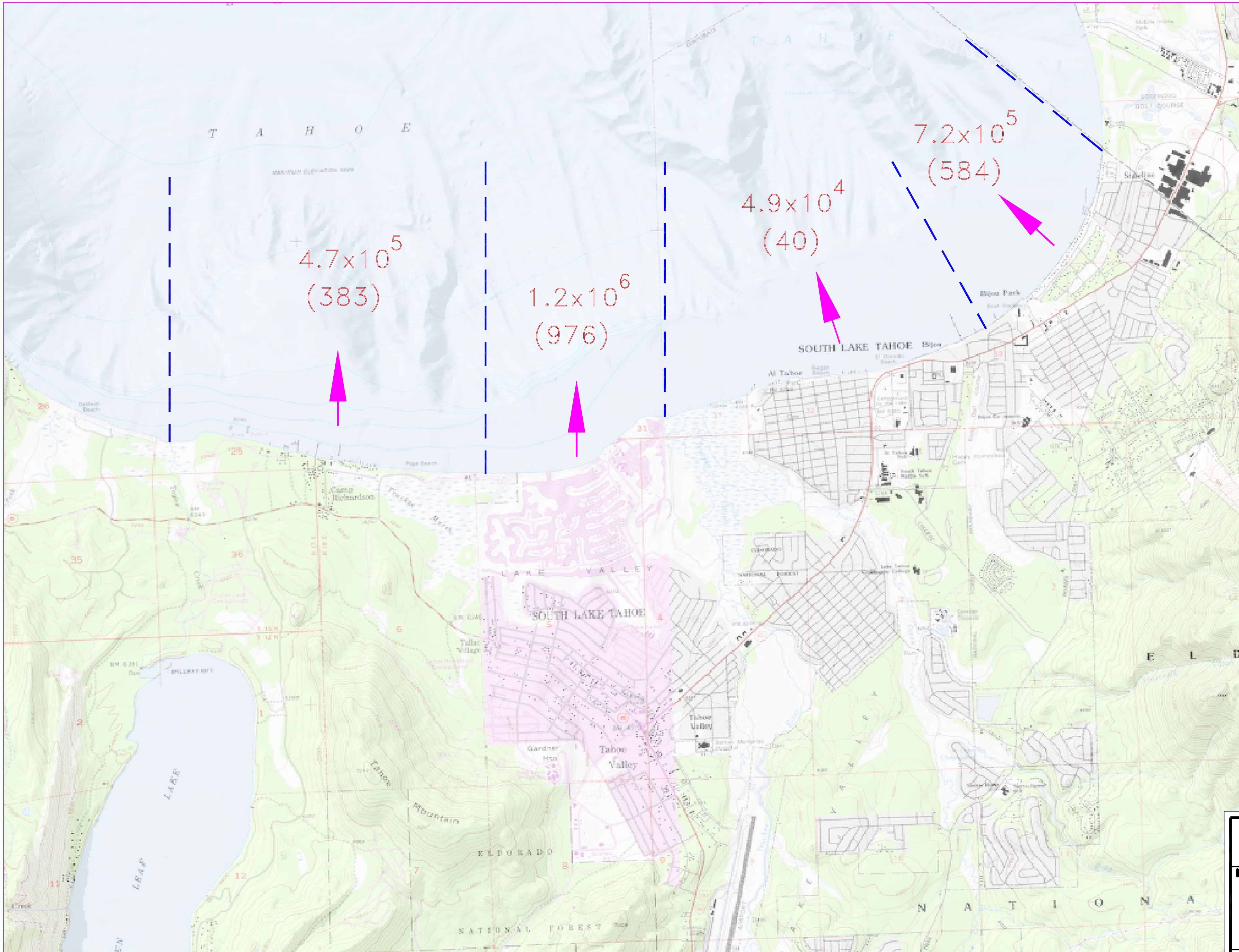
| Layer | Midpoint of Layer Elevation (ft above msl) | Total Flow into Lake m$^3$/year (acre-feet/year) | | | |
|---|---|---|---|---|---|
| | | Region 1 | Region 2 (Tahoe Keys) | Region 3 (South Lake Tahoe) | Region 4 (Stateline) |
| 2 | 6222 | $4.0\times10^5$ (328) | $1.2\times10^6$ (959) | $4.4\times10^4$ (36) | $4.7\times10^5$ (379) |
| 3 | 6205 | $5.8\times10^4$ (47) | $1.2\times10^4$ (10) | 0 (0) | $7.2\times10^4$ (58) |
| 4 | 6180 | $1.2\times10^3$ (1) | 0 (0) | 0 (0) | $1.2\times10^4$ (10) |
| 5 | 6143 | $1.2\times10^3$ (1) | $1.2\times10^3$ (1) | $1.2\times10^3$ (1) | $8.0\times10^4$ (65) |
| 6 | 6059 | $7.4\times10^3$ (6) | $6.2\times10^3$ (5) | $3.7\times10^3$ (3) | $8.9\times10^4$ (72) |
| Total | | $4.7\times10^5$ (383) | $1.2\times10^6$ (976) | $4.9\times10^4$ (40) | $7.2\times10^5$ (584) |

**Table 4-10. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Spring (Fenske 2003)**

| Layer | Midpoint of Layer Elevation (ft above msl) | Total Flow into Lake $m^3$/year (acre-feet/year) | | | |
|---|---|---|---|---|---|
| | | Region 1 | Region 2 (Tahoe Keys) | Region 3 (South Lake Tahoe) | Region 4 (Stateline) |
| 2 | 6222 | $5.7x10^5$ (461) | $1.6x10^6$ (1,287) | $8.3x10^4$ (67) | $5.6x10^5$ (454) |
| 3 | 6205 | $9.0x10^4$ (73) | $1.7x10^4$ (14) | 0 (0) | $8.5x10^4$ (69) |
| 4 | 6180 | $1.2x10^3$ (1) | $1.2x10^3$ (1) | 0 (0) | $1.5x10^4$ (12) |
| 5 | 6143 | $2.5x10^3$ (2) | $1.2x10^3$ (1) | $2.5x10^3$ (2) | $9.7x10^4$ (79) |
| 6 | 6059 | $1.1x10^4$ (9) | $1.1x10^4$ (9) | $6.2x10^3$ (5) | $1.0x10^5$ (85) |
| Total | | $6.7x10^5$ (546) | $1.6x10^6$ (1,312) | $9.0x10^4$ (73) | $8.6x10^5$ (699) |

**Table 4-11. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Fall (Fenske 2003)**

| Layer | Midpoint of Layer Elevation (ft above msl) | Total Flow into Lake $m^3$/year (acre-feet/year) | | | |
|---|---|---|---|---|---|
| | | Region 1 | Region 2 (Tahoe Keys) | Region 3 (South Lake Tahoe) | Region 4 (Stateline) |
| 2 | 6222 | $2.1x10^5$ (171) | $7.0x10^5$ (570) | 0 (0) | $3.6x10^5$ (291) |
| 3 | 6205 | $1.9x10^4$ (15) | $7.4x10^3$ (6) | 0 (0) | $5.6x10^4$ (45) |
| 4 | 6180 | 0 (0) | 0 (0) | 0 (0) | $9.9x10^3$ (8) |
| 5 | 6143 | 0 (0) | 0 (0) | 0 (0) | $5.9x10^4$ (48) |
| 6 | 6059 | $3.7x10^3$ (3) | $1.2x10^3$ (1) | $1.2x10^3$ (1) | $6.9x10^4$ (56) |
| Total | | $2.3x10^5$ (190) | $7.1x10^5$ (578) | $1.2x10^3$ (1) | $5.5x10^5$ (447) |




**LEGEND:**

7.2x10^5 (584) — GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
JUNE 2003

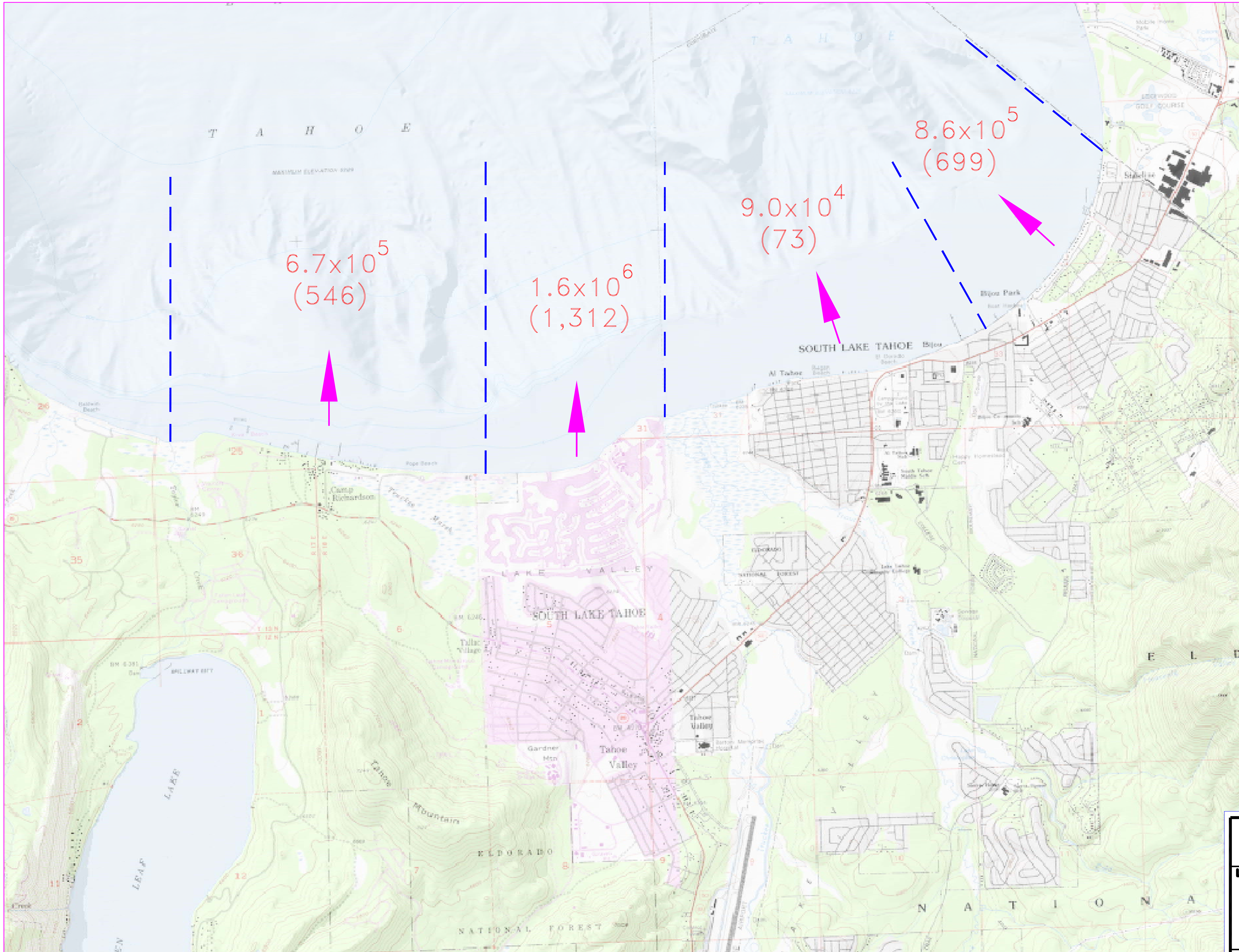
LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO LAKE TAHOE

## NORMAL YEAR– AVERAGE

| SCALE: | FIGURE: |
|---|---|
| NOT TO SCALE | 4–14 |

C:\DATA\ACAD2000\PROJECTS\M-GALE\TAFXmg00.DWG, 06/12/03, 1:1, (1/1XP




**LEGEND:**

6.7x10^5 (546) GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

TRUE N / MAGNETIC N

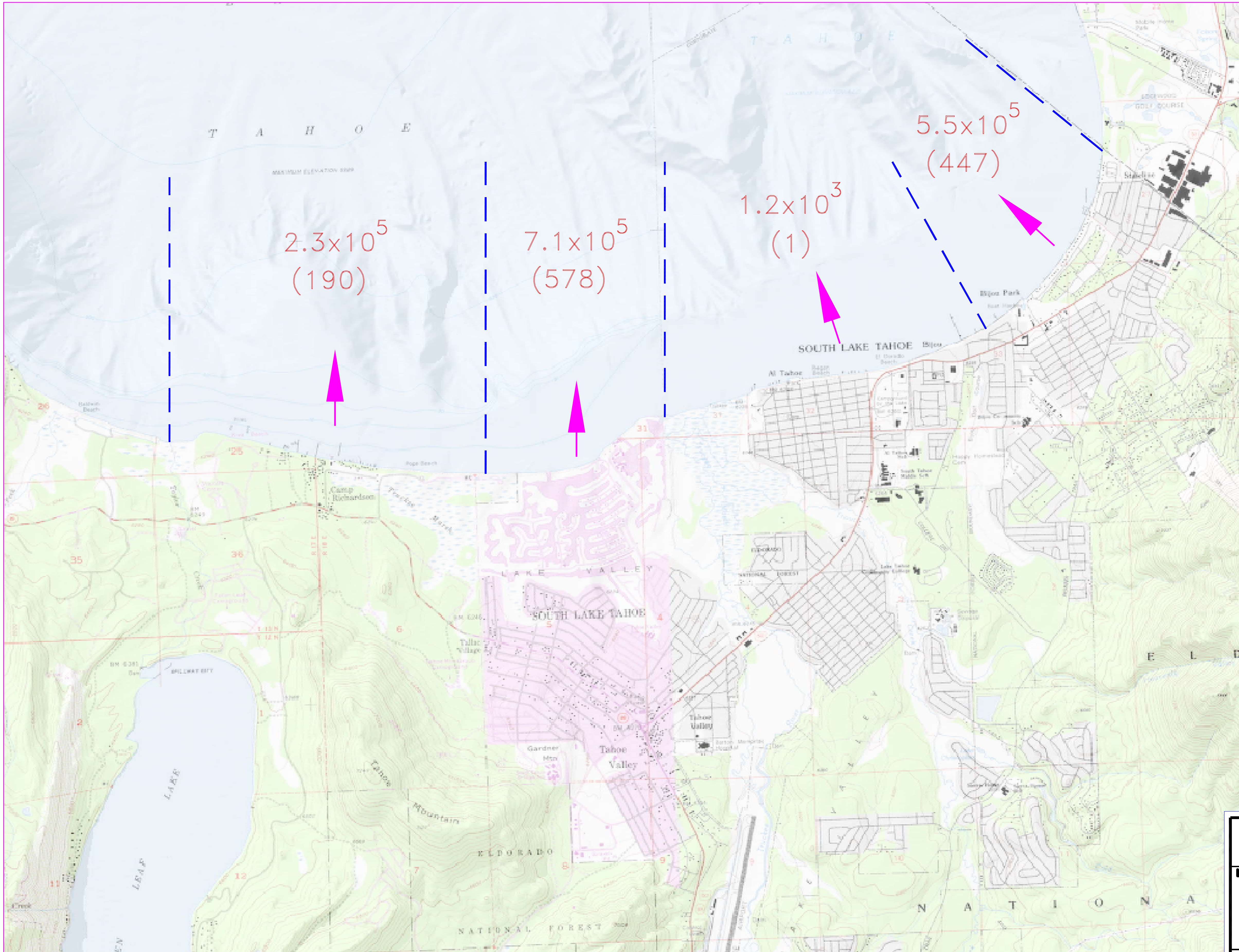
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
JUNE 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO LAKE TAHOE
SPRING AVERAGE

SCALE: NOT TO SCALE — FIGURE: 4–15

C:\DATA\ACAD2000\PROJECTS\M-CALIE\TAFXmg01.DWG, 06/12/03, 1:1, (1/1XP




**LEGEND:**

$2.3 \times 10^5$ (190) GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
JUNE 2003

LAKE TAHOE | CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO LAKE TAHOE
FALL AVERAGE

SCALE: NOT TO SCALE

FIGURE: 4-16

C:\DATA\ACAD2000\PROJECTS\M-CALIF\TAFXmg04.DWG, 06/12/03, 1:1

The area to the east of Taylor Creek and extending to Emerald Bay was not included in the model due to lack of data. The well in this area included only two groundwater level measurements. The gradients from these two measurements to the lake were 0.0018 and 0.018, averaging 0.0099. The land surface gradient in this area is similar to the average, 0.008. Using the range of gradients from 0.018 to 0.0018, a shoreline length of 1850 meters (6,070 feet), average depth of aquifer of 15 meters (50 ft) and a hydraulic conductivity of 15 m/day (50 ft/day), the discharge from this area ranges from $2.5 \times 10^5$ to $2.7 \times 10^6$ $m^3$/year (200 to 2,200 acre-feet/year). The discharge estimate using the average hydraulic gradient is $1.5 \times 10^6$ $m^3$/year (1,200 acre-feet/year).

The California/Nevada border was the western boundary of the model therefore, the Stateline area discharge estimate was calculated. As the near shore topography is similar to that of South Lake Tahoe, an estimated hydraulic gradient of 0.0028 is reasonable. Using the gradient of 0.0028, a shoreline length of 2400 meters (7,874 ft), average depth of aquifer of 15 meters (50 ft) and a hydraulic conductivity ranging from 15 to 25 m/day (50 to 82 ft/day), the discharge from this area ranges from $4.9 \times 10^5$ to $8.6 \times 10^5$ $m^3$/year (400 to 700 acre-feet/year).

## 4.5 Nutrient Loading

The potential range of nutrient discharge via groundwater from the South Lake Tahoe/Stateline area to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge for each subregion by concentrations of nutrients found in monitoring wells in the respective subregions. Details of the methodology used are described in Section 3.2.

### 4.5.1 Emerald Bay to Taylor Creek

This area only contains one well, 041, with analytical results for all nutrient forms of interest. Although this would normally be a constraint, the well is located in a significant location being close to the lake and within the predominant land use. For this reason, only one method of estimating loading was used, as it represents average, downgradient and land use weighted estimates. The average nutrient concentrations for well 041 are multiplied by the groundwater flux estimates calculated in Section 4.4. Table 4-12 summarizes the nutrient flux using this method.

The average concentrations, in conjunction with the discharge estimate using the average hydraulic gradient, $1.5 \times 10^6$ $m^3$/year (1,200 acre-feet/year), are the best representation of the average nutrient loading from the Emerald Bay to Taylor Creek region to Lake Tahoe.

**Table 4-12. South Lake Tahoe Average Annual Nutrient Loading, Emerald Bay to Taylor Creek**

| Constituent | Groundwater Flux ($m^3$/year) | Average Concentration Method: Average Concentration (mg/L) | Average Concentration Method: Nutrient Loading Estimate (kg/yr) |
|---|---|---|---|
| Ammonia + Organic | 2.7E+06 | | 122 |
| | 1.5E+06 | | 67 |
| | 2.5E+05 | 0.045 | 11 |
| Nitrate | 2.7E+06 | | 138 |
| | 1.5E+06 | | 75 |
| | 2.5E+05 | 0.051 | 13 |
| Total Nitrogen | 2.7E+06 | | 261 |
| | 1.5E+06 | | 142 |
| | 2.5E+05 | 0.096 | 24 |
| Orthophosphate | 2.7E+06 | | 193 |
| | 1.5E+06 | | 105 |
| | 2.5E+05 | 0.071 | 18 |
| Total Phosphorus | 2.7E+06 | | 231 |
| | 1.5E+06 | | 126 |
| | 2.5E+05 | 0.085 | 21 |

Notes:
1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-3.

### 4.5.2 Subregion 1

Both the average nutrient concentration and downgradient nutrient concentration methods were used for Subregion 1. The land use weighted method was not used as the wells in this region are located such that they represent the regional land use.

An average concentration for all nutrients of concern was determined for the subregion. The concentrations used to calculate the subregional averages are shown in Table 4-4. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4.

The wells in subregion 1 which best represent the downgradient concentrations are 043, 047, and 048. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. Table 4-13 summarizes the nutrient flux estimate using these methods.

The downgradient approach is the most reasonable estimate for the subregion. The downgradient wells represent the land uses of the region and would account for the accumulation or degradation of nutrients. The downgradient concentrations, in conjunction with the normal average year discharge rate, are the best representation of the average nutrient loading from subregion 1 to Lake Tahoe.

**Table 4-13. South Lake Tahoe Average & Downgradient Annual Nutrient Loading, Subregion 1**

| | | | Average Concentration Method | | Downgradient Concentration Method | |
|---|---|---|---|---|---|---|
| Constituent | Discharge Estimate Type | Groundwater Flux ($m^3$/year) | Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Downgradient Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) |
| Ammonia + Organic | Normal Average | 4.7E+05 | | 123 | | 337 |
| | Spring Average | 6.7E+05 | | 175 | | 481 |
| | Fall Average | 2.3E+05 | 0.260 | 61 | 0.714 | 167 |
| Nitrate | Normal Average | 4.7E+05 | | 15 | | 27 |
| | Spring Average | 6.7E+05 | | 21 | | 38 |
| | Fall Average | 2.3E+05 | 0.031 | 7 | 0.057 | 13 |
| Total Nitrogen | Normal Average | 4.7E+05 | | 137 | | 364 |
| | Spring Average | 6.7E+05 | | 195 | | 519 |
| | Fall Average | 2.3E+05 | 0.289 | 68 | 0.771 | 181 |
| Orthophosphate | Normal Average | 4.7E+05 | | 12 | | 15 |
| | Spring Average | 6.7E+05 | | 17 | | 22 |
| | Fall Average | 2.3E+05 | 0.025 | 6 | 0.032 | 7 |
| Total Phosphorus | Normal Average | 4.7E+05 | | 17 | | 26 |
| | Spring Average | 6.7E+05 | | 24 | | 37 |
| | Fall Average | 2.3E+05 | 0.035 | 8 | 0.055 | 13 |

Notes:

1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-4.

### 4.5.3 Subregion 2

All three methods of estimation are used in subregion 2. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so the land use weighted method of estimation is also used. Table 4-14 shows the nutrient loading estimates for all methods.

The average nutrient concentrations were calculated for dissolved nitrate and total dissolved phosphorus using the average concentrations from the wells listed in Table 4-5. Only well 050 was monitored for ammonia + organic and orthophosphorus in this subregion. To establish a better estimate for these constituents as well as total dissolved nitrogen, the concentration for ammonia + organic was estimated using the nitrate concentrations as a basis. Nitrate represented 90% of the total nitrogen in well 050. Thodal (1997) estimated that the percentage of nitrate to total nitrogen was 85%. Orthophosphorus represented 61% of the total phosphorus in well 050. Thodal (1997) estimated that the percentage of orthophosphorus to total phosphorus was 55%. Thodal's estimates were based upon a larger data set and were used for the estimation in this subregion. There are several sources of error in using the average nutrient loading method. The majority of wells used in this estimation are located a considerable distance from the lake (Figure 4-10), and do not take into account cumulative effects downgradient. The wells are clustered together and do not represent the distribution of land uses in the area.

Well 050 is the most downgradient well in this subregion. The average concentrations for this well were used in the downgradient nutrient loading estimates. This method is not ideal as the downgradient well does not represent a majority of the land use. In addition, this well is deep (Table 4-5) and would not reveal the concentrations of nutrients in the shallow aquifer where they would be expected to be higher.

The land use weighted concentration method is more appropriate for this subregion. This method takes into account the major land uses of the area to estimate the average nutrient concentrations. The predominant land uses in this subregion are commercial and residential. They each account for approximately 50% of the land use in the region. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 2.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 2 which does not have an adequate monitoring network to evaluate the nutrients in the area.

**Table 4-14. South Lake Tahoe Average , Downgradient & Land Use Weighted Annual Nutrient Loading, Subregion 2**

| | | | Average Concentration Method | | Downgradient Concentration Method | | Land Use Weighted Method | |
|---|---|---|---|---|---|---|---|---|
| Constituent | Discharge Estimate Type | Groundwater Flux ($m^3$/year) | Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Downgradient Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Land Use Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) |
| Ammonia + Organic | Normal Average | 1.2E+06 | | 138 | | 52 | | 249 |
| | Spring Average | 1.6E+06 | | 186 | | 70 | | 335 |
| | Fall Average | 7.1E+05 | 0.115 | 82 | 0.043 | 31 | 0.207 | 148 |
| Nitrate | Normal Average | 1.2E+06 | | 816 | | 451 | | 530 |
| | Spring Average | 1.6E+06 | | 1097 | | 607 | | 712 |
| | Fall Average | 7.1E+05 | 0.678 | 483 | 0.375 | 267 | 0.440 | 314 |
| Total Nitrogen | Normal Average | 1.2E+06 | | 955 | | 503 | | 779 |
| | Spring Average | 1.6E+06 | | 1283 | | 676 | | 1047 |
| | Fall Average | 7.1E+05 | 0.793 | 565 | 0.418 | 298 | 0.647 | 461 |
| Orthophosphate | Normal Average | 1.2E+06 | | 26 | | 22 | | 104 |
| | Spring Average | 1.6E+06 | | 36 | | 29 | | 139 |
| | Fall Average | 7.1E+05 | 0.022 | 16 | 0.018 | 13 | 0.086 | 61 |
| Total Phosphorus | Normal Average | 1.2E+06 | | 47 | | 35 | | 143 |
| | Spring Average | 1.6E+06 | | 63 | | 47 | | 193 |
| | Fall Average | 7.1E+05 | 0.039 | 28 | 0.029 | 21 | 0.119 | 85 |

Notes:

1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-5.

### 4.5.4 Subregion 3

All three methods of estimation are used in Subregion 3. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so this method of estimation is also used. Table 4-15 shows the nutrient loading estimates for all methods.

The average nutrient concentrations were calculated for dissolved nitrate and total dissolved phosphorus using the average concentrations from the wells listed in Table 4-6. Only wells 045 and 049 were monitored for ammonia + organic and orthophosphorus in this subregion. To establish a better estimate for these constituents as well as total dissolved nitrogen, the concentration for ammonia + organic was estimated using the nitrate concentrations as a basis. Again, Thodal's estimates of 85% nitrate and 55% orthophosphorus were used in this subregion based upon a larger data set. The average concentration approach is not suited for this area as most of the wells are screened within the deep aquifer. This method neglects those concentrations found in the shallow aquifer and bias the estimates to lower concentrations. The potential accumulation of nutrients downgradient is not accounted for in the averaging method.

Well 039 is the most downgradient well in this subregion with nutrient concentrations reported. The downgradient approach is not the best method to use in this subregion. The well is located approximately 450 meters (1,476 ft) from the shore and does not represent downgradient concentrations. These well is deep, neglecting the shallow aquifer.

The land use weighted method is the most appropriate for the region. This takes into account the primary land use and provides an estimation over a range of aquifer depths. The predominant land uses in this subregion are vegetated, residential and commercial representing approximately 50%, 33% and 17% of the land use in the region, respectively. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 3.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 3 which does not have an adequate monitoring network to evaluate the nutrients in the area.

**Table 4-15. South Lake Tahoe Average, Downgradient & Land Use Weighted Annual Nutrient Loading, Subregion 3**

| | | | Average Concentration Method | | Downgradient Concentration Method | | Land Use Weighted Method | |
|---|---|---|---|---|---|---|---|---|
| Constituent | Discharge Estimate Type | Groundwater Flux ($m^3$/year) | Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Downgradient Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Land Use Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) |
| Ammonia + Organic | Normal Average | 4.9E+04 | | 5 | | 5 | | 14 |
| | Spring Average | 9.0E+04 | | 9 | | 9 | | 26 |
| | Fall Average | 1.2E+03 | 0.099 | 0 | 0.097 | 0 | 0.292 | 0 |
| Nitrate | Normal Average | 4.9E+04 | | 17 | | 27 | | 25 |
| | Spring Average | 9.0E+04 | | 31 | | 50 | | 45 |
| | Fall Average | 1.2E+03 | 0.346 | 0 | 0.550 | 1 | 0.497 | 1 |
| Total Nitrogen | Normal Average | 4.9E+04 | | 22 | | 32 | | 39 |
| | Spring Average | 9.0E+04 | | 40 | | 58 | | 71 |
| | Fall Average | 1.2E+03 | 0.444 | 1 | 0.647 | 1 | 0.789 | 1 |
| Orthophosphate | Normal Average | 4.9E+04 | | 1 | | 1 | | 4 |
| | Spring Average | 9.0E+04 | | 2 | | 2 | | 8 |
| | Fall Average | 1.2E+03 | 0.021 | 0 | 0.021 | 0 | 0.091 | 0 |
| Total Phosphorus | Normal Average | 4.9E+04 | | 2 | | 2 | | 6 |
| | Spring Average | 9.0E+04 | | 3 | | 4 | | 11 |
| | Fall Average | 1.2E+03 | 0.033 | 0 | 0.039 | 0 | 0.124 | 0 |

Notes:

1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-6.

### 4.5.5 Subregion 4

All three methods of estimation are used in Subregion 4. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so this method of estimation is also used. Table 4-16 shows the nutrient loading estimates for all methods.

An average concentration for all nutrients of concern was determined for the subregion. The concentrations used to calculate the subregional averages are shown in Table 4-7. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4. Many of the sampling points in this region are chosen to monitor specific nutrient sources. This increases the concentration for the region, as much of the other land uses are not represented.

The wells in subregion 4 which best represent the downgradient concentrations are 024, and 031. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. Table 4-13 summarizes the nutrient flux estimate using these methods. The downgradient wells are again designed to monitor specific sources. This may introduce errors when using this as an estimation for the entire region.

The land use weighted option is the most appropriate for this region. This method considers the type of land use in the region to apply average concentrations. The predominant land uses in this subregion are residential, commercial and vegetated. Commercial and vegetated land uses represent approximately ¼ and $^{1}/_{8}{}^{th}$ of the land use in the region, respectively. The remaining area is predominantly residential. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 4.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 4 which does not have an adequate monitoring network to evaluate the nutrients in the area. The land use weighted average and normal average year discharge provide the best estimation of nutrient loading for this region.

**Table 4-16. South Lake Tahoe Average, Downgradient and Land Use Weighted Annual Nutrient Loading, Subregion 4**

| | | | Average Concentration Method | | Downgradient Concentration Method | | Land Use Weighted Method | |
|---|---|---|---|---|---|---|---|---|
| Constituent | Discharge Estimate Type | Groundwater Flux ($m^3$/year) | Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Downgradient Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Land Use Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) |
| Ammonia + Organic | Normal Average | 7.2E+05 | | 385 | | 259 | | 176 |
| | Spring Average | 8.6E+05 | | 461 | | 310 | | 211 |
| | Fall Average | 5.5E+05 | 0.535 | 295 | 0.359 | 198 | 0.245 | 135 |
| Nitrate | Normal Average | 7.2E+05 | | 538 | | 285 | | 310 |
| | Spring Average | 8.6E+05 | | 644 | | 341 | | 371 |
| | Fall Average | 5.5E+05 | 0.747 | 412 | 0.396 | 218 | 0.430 | 237 |
| Total Nitrogen | Normal Average | 7.2E+05 | | 1086 | | 544 | | 486 |
| | Spring Average | 8.6E+05 | | 1300 | | 651 | | 581 |
| | Fall Average | 5.5E+05 | 1.508 | 831 | 0.755 | 416 | 0.674 | 372 |
| Orthophosphate | Normal Average | 7.2E+05 | | 86 | | 48 | | 61 |
| | Spring Average | 8.6E+05 | | 103 | | 57 | | 73 |
| | Fall Average | 5.5E+05 | 0.119 | 66 | 0.066 | 36 | 0.085 | 47 |
| Total Phosphorus | Normal Average | 7.2E+05 | | 37 | | 86 | | 86 |
| | Spring Average | 8.6E+05 | | 45 | | 103 | | 103 |
| | Fall Average | 5.5E+05 | 0.052 | 29 | 0.119 | 66 | 0.119 | 66 |

Notes:

1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-7.

### 4.5.6 Stateline

The Stateline area wells are dispersed throughout the area, providing a representative network. The wells are located in areas with a variety of land uses, and downgradient wells are present along the shoreline. For this reason, only the average and downgradient methods are applied. Table 4-17 shows the nutrient loading estimates for all methods.

An average concentration for all nutrients of concern was determined for the area. The concentrations used to calculate the subregional averages are shown in Table 4-8. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4.

The downgradient wells in this region are 003, 197, 199 and 200. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. The average nutrient concentrations for these wells was determined for use in estimating nutrient loading.

The downgradient approach is the most accurate in this region. The wells are positioned to monitor a variety of land uses and are close enough to the lake to show representative concentrations of nutrients that could be entering the lake. The downgradient nutrient concentrations and groundwater discharge rate of 8.6 x $10^5$ $m^3$/year (700 acre-feet/year) are considered the most reasonable estimation of nutrient loading to Lake Tahoe from this area.

**Table 4-17. Stateline Average & Downgradient Annual Nutrient Loading**

| | Average Concentration Method | | Downgradient Concentration Method | |
|---|---|---|---|---|
| Groundwater Flux ($m^3$/year) | Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) | Downgradient Average Concentration (mg/L) | Nutrient Loading Estimate (kg/yr) |
| 4.9E+05 | | 180 | | 317 |
| 8.6E+05 | 0.365 | 315 | 0.642 | 554 |
| 4.9E+05 | | 480 | | 54 |
| 8.6E+05 | 0.972 | 839 | 0.110 | 95 |
| 4.9E+05 | | 660 | | 371 |
| 8.6E+05 | 1.337 | 1154 | 0.752 | 649 |
| 4.9E+05 | | 7 | | 10 |
| 8.6E+05 | 0.015 | 13 | 0.020 | 17 |
| 4.9E+05 | | 11 | | 17 |
| 8.6E+05 | 0.023 | 20 | 0.034 | 29 |

Notes:
1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-8.

## 4.6 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 867 kg/year (1,911 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 326 kg/year (719 lbs/yr). Table 4-18 summarizes the loading estimates.

**Table 4-18. South Lake Tahoe/Stateline Ambient Nutrient Loading Estimate**

| Subregion | Groundwater Discharge ($m^3$/year) | Ambient Total Dissolved Nitrogen (mg/L) | Ambient Total Dissolved Phosphorus (mg/L) | Ambient Nitrogen Nutrient Loading (kg/year) | Ambient Phosphorus Nutrient Loading (kg/year) |
|---|---|---|---|---|---|
| Emerald Bay to Taylor Creek | 1.48E+06 | | | 268 | 101 |
| Subregion 1 | 4.72E+05 | | | 86 | 32 |
| Subregion 2 | 1.20E+06 | 0.181 | 0.068 | 218 | 82 |
| Subregion 3 | 4.93E+04 | | | 9 | 3 |
| Subregion 4 | 7.20E+05 | | | 130 | 49 |
| Stateline | 8.63E+05 | | | 156 | 59 |
| Total | | | | 867 | 326 |

Notes:

1. 1 $m^3$/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

## 4.7 Summary & Conclusions

The South Lake Tahoe/Stateline area has the largest monitoring network in the basin. This provides the best dataset available to calculate nutrient loading to Lake Tahoe. For this reason, a groundwater flow model was developed. The model encompassed all of this area except Taylor Creek to Emerald Bay and Stateline. The groundwater discharge estimates for the areas not modeled are computed in a similar manner as the rest of the basin.

The groundwater discharge estimates for the subregions ranged from 1.2 x $10^3$ $m^3$/year to 2.7 x $10^6$ $m^3$/year (1 acre-ft/year to 2,200 acre-ft/year). The broad range of values is due to municipal drinking water supply well pumping in subregion 3 and no pumping and a steeper gradient in the Emerald Bay to Taylor Creek area. A number of methods were used to provide a range of nutrient loading estimates for each region. The most reasonable estimate for each region is included in Table 4-19.

**Table 4-19. South Lake Tahoe/Stateline Total Dissolved Nitrogen and Total Dissolved Phosphorus Loading Estimate Summary by Subregion**

| | Nutrient Loading Estimate (kg/year) | | | | | | |
|---|---|---|---|---|---|---|---|
| Constituent | Emerald Bay to Taylor Creek | Subregion 1 | Subregion 2 | Subregion 3 | Subregion 4 | Stateline | Total |
| Total Nitrogen | 142 | 364 | 779 | 39 | 486 | 649 | 2,459 |
| Total Phosphorus | 126 | 26 | 143 | 6 | 86 | 29 | 416 |

Comparing the total groundwater nutrient loading (Table 4-19) to the ambient nutrient loading (Table 4-18), natural processes may make up to 35% of the nitrogen and 78% of the total dissolved phosphorus loading to the lake.

The South Lake Tahoe/Stateline Area has an extensive monitoring network, however the placement of many of the wells are not representative of the nutrient concentrations that may be entering the lake through groundwater. Subregion 2 and subregion 4 are prime candidates for a better placed monitoring network, as the wells currently are not placed to properly evaluate all the potential sources. While subregion 3 does not have an adequate monitoring network, the lack of significant discharge (Fenske 2003) to the lake in this area reduces the amount of loading originating from the region. The evaluation shows that subregion 2 and the Emerald Bay to Taylor Creek area potentially discharge the highest concentrations of nitrogen and phosphorus for the region, respectively. These estimates would place the two subregions as top priorities for future investigation or mitigation in South Lake Tahoe/Stateline.

Additional downgradient monitoring points would be beneficial in the Tahoe Keys area. The wells in this region are located approximately 2,800 meters (9,186 ft) from the lake. There are no wells that are sufficient to characterize groundwater near the lake. A cluster of wells installed to define the nutrient concentrations with depth would provide better information on the distribution of nutrients with depth.

The area between wells 024 and 013 in subregion 4, near the lake shore, would be a good addition to the monitoring network. Again, many of the wells are located too far from shore to provide a good estimation of nutrients near the lake.

Although well placement is acceptable in the Emerald Bay to Taylor Creek area, the groundwater level measurements and geology are not clearly defined. This region should be targeted for additional groundwater level measurements to better define the gradient for the region. The geology should be further investigated in this area, as well as the remainder of the region.

Bergsohn has conducted a study to determine depth to bedrock, but the intervening zones require additional investigation. An understanding of the stratigraphy of South Lake Tahoe is critical for evaluating contaminant and nutrient transport towards Lake Tahoe and their redistribution within the basin. Current models are based mainly on deep production wells drilled for STPUD and geophysically logged. Although this is a valuable dataset, each log represents a point measurement showing vertical changes in material types. Then, the data must be extrapolated between wells. To reduce potential for interpreter error, surface geophysical investigations should be run along key transects, both parallel and transverse to the shoreline. These data can be used to better define lateral continuity of major reflecting surfaces. Select, continuously cored test pilot holes should then be drilled to validate material types to ground truth the surface geophysics. Such geophysical surveys should include seismic reflection surveys to define general stratigraphic patterns and the basement geometry. Where shallow stratigraphic information is required, ground-penetrating radar surveys should be conducted to acquire high-resolution information for the upper 18 m to 40 m (60 to 100 ft).

Because of the multitude of land uses in the region, it is difficult to determine the contribution of nutrients from various sources. Specific land use types should be targeted for additional monitoring to better understand each as a contributor. Examples of land uses that require additional investigation are residential areas that are fertilized vs. those that prefer natural vegetation. Ball fields and urban parks should be targeted for additional information. South Lake Tahoe also contains numerous dry wells. The effects from these and other infiltration basins and trenches are unknown. Studies are underway or planned to monitor the effects from infiltration basins.

Additional data gaps for this area can be found in Appendix B.

The results of the South Lake Tahoe/Stateline area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000). Comparing these values, the South Lake Tahoe/Stateline area represents only 4.1% of the nitrogen and 10.4% of the phosphorus nutrient loading from groundwater to Lake Tahoe.

**Table 4-20. South Lake Tahoe/Stateline Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)**

| | Nitrogen | Phosphorus | Dissolved Phosphorus |
|---|---|---|---|
| **U.S. Forest Service Watershed Assessment Results, Basin-Wide** | | | |
| Estimated annual nutrient loading from all sources (kg) | 418,100 | 45,700 | 17,000 |
| Estimated annual nutrient loading from groundwater (kg) | 60,000 | 4,000 | 4,000 |
| **Corps Groundwater Evaluation Results, South Lake Tahoe/Stateline Area** | | | |
| Estimated annual nutrient loading from groundwater (kg) | 2,459 | 416 | 416 |
| Estimated percent of annual nutrient loading from all sources | 0.59% | 0.91% | 2.4% |
| Estimated percent of annual nutrient loading from groundwater | 4.1% | 10.4% | 10.4% |